WORKSHOP REPORT

1. MNES Sanction No : 10/9/2001 - ST dated 14 January 2002
2. Name of Nodal Agency : TERI
3. Venue : Hotel Brahmaputra Ashok, Guwahati
4. Dates of the workshop : 13 – 15 March 2002
5. No of participants : 38
6. List of supporting documents enclosed with the report

   i. Workshop report and photographs
   ii. List of participants
   iii. List of topics covered (Agenda)
   iv. Copy of proceedings
   v. Utilization certificate
   vi. Audited statement of accounts

7. Remarks if any on the programme

Signature
Head of the Organisation

Regional workshop on solar and low energy architecture

Organised by TERI North Eastern Regional Centre, Guwahati
13-15 March 2002, Hotel Brahmaputra Ashok, Guwahati

Workshop Report

The three-day *Regional workshop on solar and low energy architecture* was held during 13-15 March 2002 at Hotel Brahmaputra Ashok, Guwahati. The objective of the workshop was to create awareness about energy efficient designs by optimum use of available solar energy and other forms of ambient energy in building energy management and train the participants in the application of solar and low energy architectural concepts. There were 38 participants comprising of architects, civil engineers and representatives of state renewable energy development agencies, State PWD, Universities and Research institutions from various parts of the Northeast. The workshop comprised of seven sessions in three days: inaugural session, five technical sessions and a panel discussion.

Day 1: 13 march 2002

Inaugural session

The inaugural session was presided over by Mr AK Baruwa, Director, Assam Science Technology & Environment Council (ASTEC). Welcoming the distinguished guests and the participants. Mr Debajit Palit, Research Associate, TERI and Coordinator of the workshop, briefed about the objectives of the programme. Ms Mili Mazumdar, Fellow, TERI apprised the audience about the building energy activities at TERI and TERI's initiatives and experience in design of energy efficient buildings. Mr P K Rajkhowa. Regional Chief, HUDCO spoke about the role played by HUDCO in the design and construction of sustainable habitats. Mr Baruwa in his presidential address informed the participants about the initiatives taken by MNES and ASTEC in promoting solar passive buildings. He emphasized the need for low energy and solar passive buildings and urged the architects and engineers to design such buildings. The session concluded with the vote of thanks by Mr Debajit Palit.

Technical Session 1

The technical session 1 commenced with Ms Mili Mazumdar of TERI delivering a lecture on the topic *Bioclimatic architecture in India and green buildings*. Ms Mazumdar's presentation included an overview of sustainable building design, climatic classification of India. climatic response, concept and design of green buildings and simple and advanced concepts of passive architecture. The speaker illustrated her talk with different case studies of energy efficient buildings in India. The session concluded with a presentation on *blended cement* by Mr P K Vasist of Vinay Cements Ltd.

Day 2: 14 March 2002

Technical Session 2 & 3

The second day commenced with Technical session 2 on the theme "*Renewable energy technologies in buildings*". Mr Sadhan Mahapatra, Lecturer in the Department of Energy, Tezpur University started the day with a presentation on the topic *solar energy resources and its utilization*. Mr Mahapatra detailed about the various forms of solar energy conversions and its enduses. This was followed by a presentation on *solar water heating systems* (operating principle, technology, manufacturing status, marketing and servicing infrastructure, design and sizing, effect of change in angle on the efficiency, design and detailing parameters) by Mr M K Choudhury, Scientific Officer of Assam Science Technology and Environment Council, Guwahati. This was followed by the lecture on *solar photovoltaic technology*- operating and design principles, manufacturing status, economics, marketing and servicing infrastructure by Mr Debajit Palit, Research Associate, TERI NE Centre. The session concluded with Mr Saugata Dutta of Tata BP Solar delivering a lecture on the topic *solar PV in buildings*.

The Technical session 3 comprised of presentation of case studies by Ms Mili Mazumdar and Ms Sakuntala Ghosh, Director, Ghosh Bose & Associates, Kolkata. Ms Mazumdar discussed in detail about the building & lighting design and landscaping of the RETREAT building of TERI in Gurgaon, Haryana. Mrs Ghosh presented the case study of the West Bengal Pollution Control Board building in Kolkata. The day concluded with demonstration of VisualDOE software to the participants.

Day 3: 15 March 2002

Technical Session 4 & 5

The morning session of the concluding day started with the Technical session 4 on the theme "*Low cost housing technologies*". Architect Bipul Kr Das of Design Nucleus, Guwhati and Mr Kamesh Salam, Coordinator, Cane & Bamboo Technology Centre, Guwahati discussed in detail about the use of bamboo as a low energy building material, which is found abundantly in the northeastern region. Mr Salam then showed a video presentation on the construction techniques of bamboo houses. A lecture on construction of low cost houses using ferrocement technology was also delivered by Dr U C Kalita, Head of the department of Civil Engineering, IIT-Guwahati. The session concluded with the presentation by Mrs N Hazarika of HUDCO, who gave an overview of the different HUDCO schemes and the low cost technologies disseminated by HUDCO through its various building centres.

The post lunch session (Technical session 5) commenced with presentation by Mr D R Das, Principal Scientific Officer and Head (NER), MNES on the financial incentives available for construction of solar passive buildings and installation of various renewable energy systems. Ms Mili Mazumdar then presented the lecture on the topic *daylighting-design and integration with artificial lighting* wherein she discussed about the design tools for daylight integration into buildings, daylighting components and integration of daylighting with artificial lighting and also presented some case studies for illustration.

Panel discussion

The workshop concluded with a panel discussion on the theme '*sustainable habitat and north eastern region*" with Architect Upen Kakoti in the Chair. The other panelists were Ms Mili Mazumdar of TERI, Mrs Sakuntala Ghosh of Ghosh Bose and Associates, Kolkata and Mr D R Das of MNES. Various issues were discussed in the panel discussion and different recommendations were put forwarded by the participants.

Recommendations

1. The Ministry of Non Conventional Energy Sources (MNES) should continue their support for using solar and low energy features in Govt. and Semi Govt. building. The state renewable energy development agencies should vigorously take up the issue of incorporating solar passive features in buildings designed and constructed by the state PWD and also influence the different Govt. and Semi Govt. agencies for construction of solar passive buildings.
2. Existing building bylaws in the region may be suitably amended by the Town and Country Planning department and development authorities to ensure integration of renewable energy systems such as solar water heaters in the buildings and application of solar passive concepts in the buildings.
3. MNES should motivate the people through both print and electronic media for construction of solar passive buildings. In addition, MNES should give cent percent financial support for a pilot solar passive building project in the region for demonstration.
4. Incentives in the form of proportionate lower tariffs may be given to hospitals, nursing homes, hotels etc by state electricity boards for using low energy devices.
5. There should be close coordination between MNES, TERI, ASTEC and Association of Architects, Assam (AAA) for awareness generation and implementation of projects using solar passive concepts. TERI and HUDCO may be requested to give technical backup support for construction of solar passive buildings in the region. A working group may also be formed with representatives of AAA, ASTEC, HUDCO and TERI for preparation of a proper database on climatological and environmental data for implementation of solar passive concepts and MNES may be approached for financial support for the same.
6. A paper on solar and low energy architecture should be included in the curriculum of degree and diploma level architecture course of all university.

Regional workshop on solar and low energy architecture

Organised by TERI North Eastern Regional Centre, Guwahati
Sponsored by MNES, New Delhi, HUDCO & Vinay Cements
Hotel Brahmaputra Ashok, Guwahati
13-15 March 2002

List of participants

SN	Name	Organisation	Contact no
1.	**Mr A K Baruwa**	Director, ASTE Council, Silpukhuri, Guwahati 781 003	0361-668475
2.	**Mr Sadhan Mahapatra**	Lecturer, Dept. of Energy Tezpur University, Tezpur 784 028	03712- 67107
3.	**Ms Sakuntala Ghosh**	Ghosh Bose & Associates, 8 Ho Chi Minh sarani, Kolkata 700 071	-
4.	**Er Sunshine Marbaniang**	Project Engineer, MNREDA, Mawpet (Near BSF), Shillong 793 012	0364- 537343
5.	**Ar Atonu Baruah**	Asst. Architect, PWD (Bldg), Chandmari, Guwahati 781 003	0361- 556463
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9.	**Mr Ratul Nath**	Dept. of Energy, Tezpur University, Napaam, Tezpur 784 028	03712- 67107
10.	**Ar J K Bezbaruah**	Directorate of Physical Plant, Assam Agricultural University, Jorhat	0376 -3321521
11.	**Mr D C Goswami**	Project Engineer, NEITCO, Bhangagarh, Guwahati 781 005	0361-529158
12.	**Er M K Choudhury**	Scientific Officer, ASTE Council , Silpukhuri, Guwahati 781 003	0361- 664415
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15.	**Ar Upen Kakati**	Upen Kakati & Associates, Arunadoy Path, Guwahati 781005	0361-344810
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17.	Ar Ashanka Sarmah	Design Team North Eastern, J B Road, Chenikuthi, Guwahati 3	0361-661 694
18.	Mr Birendra Kr Bora	Dy Chief Technical Auditor, Oil India Ltd, Duliajan 786 602	0374-800447
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22.	Ar Dinesh Bhattacharya	Design Consortium, Panbazar, Guwahati 781 001	0361- 547273
23.	Mr Kailash Barua	Flamingo Tours & Travels, R G Baruah Road Guwahati 781 024	0361- 454669
24.	Dr Bipul Talukdar	Lecturer, Assam Engineering College, Jalukbari, Guwahati 781013	0361- 550787
25.	Dr M K Kalita	Registrar, IASST, Khanapara, Guwahati 781 022	0361-260859
26.	Er K S Lahakar	Chief Project Engineer, IASST, Khanapara, Guwahati 781 022	0361 -260859
27.	Ar Ranojoy Sen	Planning Consortium, Sarvoday Path, GS Road, Guwahati -5	0361-528 820
28.	Er Tapan Kr Dutta	Srimanta Sankardeva Kalakshetra, Panjabari, Guwahati 781037	0361-337382
29.	Ms N Hazarika	HUDCO, Ganeshguri Guwahati 781 005	0361-202173
30.	Mr P Konwer	HUDCO, Ganeshguri Guwahati 781 005	0361-202173
31.	Ar Anjit Choudhury	A Choudhury & Associates, Tayabulla Road, Guwahati 781 001	0361 511490
32.	Ar Bipul Kr Das	Design Nucleus, Apurba Sinha Path, R G Barua Road, Guwahati	0361- 453073
33.	Prof. Amar Yumnam	HOD, Dept. Of Economics, Manipur University	-
34.	Ar Mili Mazumdar	Fellow, TERI, India Habitat Centre, New Delhi 110003	011-4682100
35.	Mr Debajit Palit	Research Associate, TERI, 503, Orion Tower, Dispur Guwahati	0361-264363
36.	Mr Asif Ali Hazarika	TERI, 503, Orion Tower, Dispur Guwahati	0361-264363
37.	Mr Dipankar Saharia	Research Associate, TERI, 503, Orion Tower, Dispur Guwahati	0361-264363
38.	Dr U C Kalita	HOD, Dept. of Civil Engineering, IIT-Guwhati, Guwhati 781039	0361-690321-8

Regional workshop on solar and low energy architecture

Hotel Brahmaputra Ashok, Guwahati
13-15 March 2002

Agenda

Day 1: 13 March 2002

14:00–14 40	Registration
14: 40–15.40	**Inaugural session**
	Welcome address – Mr Debajit Palit, TERI
	Address – Ms Mili Mazumdar, Fellow TERI
	Address - Mr P K Rajkhowa, Regional Chief, HUDCO, Guwahati
	Presidential address – Mr A K Baruwa, Director, Assam Science, Tech & Environment Council
	Vote of thanks
15: 40-16.00	*Tea*
16:00 – 17:30	**Technical session I:** ***Energy efficiency in architecture***
16:00 – 17 00	Bioclimatic architecture in India – Ms Mili Majumdar, TERI - Delhi
17:20 – 18:00	Blended cements – Mr P K Vasist, Chief Marketing Officer, Vinay Cements Ltd
18:00–19:00	*High tea*

Day 2: 14 March 2002

10:00–13:00	**Technical session II:** ***Renewable energy technologies in buildings***
10:00–10:35	Principles of solar energy and its utilization– Mr S Mahapatra, Lecturer, Tezpur University
10:35–11 10	Solar water heating system- technology, design, sizing & case studies to highlight architectural integration– Mr M K Choudhury, Scientific Officer, ASTEC, Guwahati
11:10 –11.25	*Tea*
11:25–12.00	Solar Photovoltaic systems– Mr Debajit Palit, Research Associate, TERI - Guwahati
12:00–13.00	Solar PV in buildings – Mr Saugata Dutta, Head- Eastern Region, Tata BP Solar India Ltd
13:00–14 00	*Lunch*
14.00-17:00	**Technical Session III: Case studies**
14:00-14 40	RETREAT- An energy efficient building - Ms Mili Majumdar, Fellow, TERI- Delhi
14:40-15 15	WBPCB building – Ms Sakuntala Ghosh, Ghose Bose & Associates, Kolkata
15:15-15.30	*Tea*
15:30-16.30	Demo on VisualDOE software – Ms Mili Majumdar, TERI- Delhi

Day 3: 15 March 2002

10.00-13.00	**Technical Session IV:** ***Low cost housing technologies***
10:00-10 50	Bamboo. A low cost & low energy construction material –Mr Bipul Das, Architect, Guwahati
10:50-11:20	Bamboo housing around the world – Mr Kamesh Salam – Coordinator, CBTC, Guwahati
11:20-11:30	*Tea*
11:30-12:30	Construction of low cost houses– Dr U C Kalita, Head, Civil Engg. Dept, IIT Guwahati
12:30-13:00	Innovative construction technology and alternative building material – HUDCO
13:00-14:00	*Lunch*
14.00-15.00	**Technical Session V**
14:00- 14:20	Financial incentives by MNES – Mr D R Das, PSO & Head, MNES NE Regional office
14:20–15.00	Day lighting architecture and energy efficient lighting— Ms Mili Majumdar, TERI- Delhi
15:00–16.30	**Panel discussion:** ***Sustainable habitat and North eastern Region***
16:30 –16:40	*Wrap up and Tea*

REGIONAL WORKSHOP ON SOLAR AND LOW ENERGY ARCHITECTURE

SPONSORED BY
MINISTRY OF NON CONVENTIONAL ENERGY SOURCES
HUDCO, NEWDELHI
VINAY CEMENTS LTD, GUWAHATI

ORGANISED BY
TERI NORTH EASTERN REGIONAL CENTRE, GUWAHATI

13-15 MARCH 2002, GUWAHATI

teri

TATA ENERGY RESEARCH INSTITUTE

Traditional Architecture and Use of Energy Conserving Concepts in Modern Buildings

N. K. Bansal

Introduction

Over many centuries examples of building design and building techniques have been developed in regions with different climatic conditions, resulting in structures that provide varying levels of comfort inside the building space without the use of any sophisticated technical device. As in various parts of the world, vernacular architecture in India generally exhibits the indigenous use of locally available materials and techniques, to build buildings that are adapted to local climatic conditions. As discussed earlier, the climate in various parts of India ranges from extremely hot desert conditions to high altitude locations with severe, cold conditions. Very broadly, India can be divided into six climatic zones. A study of vernacular architecture brings out many concepts and design patterns relevant for energy efficient building design.

Energy Efficienct Features and Concepts

An examination of traditional buildings brings out many attractive features of design, which are valid even for contemporary architecture.

Leh, the capital of Ladakh, has very cold climatic conditions with low precipitation. The common material used for building is mud with very thick walls. This construction helps to reduce the temperature variation indoors, inspite of the large diurnal fluctuations of ambient temperature. The living areas here are usually on the first floor. The ground floor is meant for the animals and the second floor is for the kitchen. The living space is thus sandwiched between the two heat sources (Fig. 1). Another common feature of most houses in Leh is very small openings so the heat losses are reduced. The kitchen is used as the daytime living space in these regions, to benefit from warmth of the cooking stove.

Another striking example of climatic conscious building design is the vernacular architecture in the hot and dry regions of Rajasthan (Fig 2). The building form in this region results in minimum surface area and heavy insulation in the form of thatch on the roof.

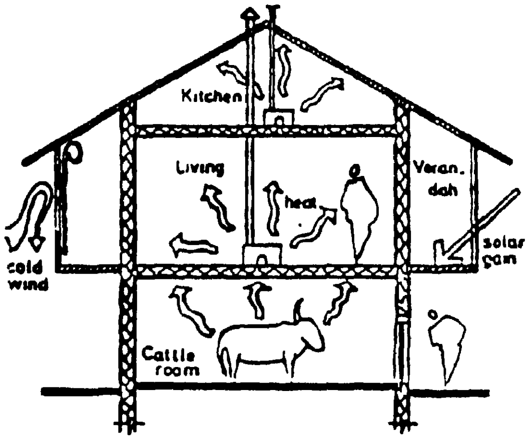

Fig. 1: Passive features for cold climates.

- Increase of solar heat gain
  - by facing the longer side towards south, to catch maximum sun in winter
  - by providing a sheltered verandah for use on sunny days
- Increase of internal heat gain
  - by utilizing heat from cattle accommodated below the living space
  - by utilizing the kitchen stove as a fireplace and placing the living room between two warm spaces (cattle room and kitchen)
- Decrease of heat loss
  - by low entrances to cattle room and living spaces
  - by reducing exposure to cold winter breeze, with canvas hung around the verandah, creating a buffer zone
  - by locating the house on the leeward side of a hill
- Balance of temperature fluctuations
  - by thick stone/mud walls

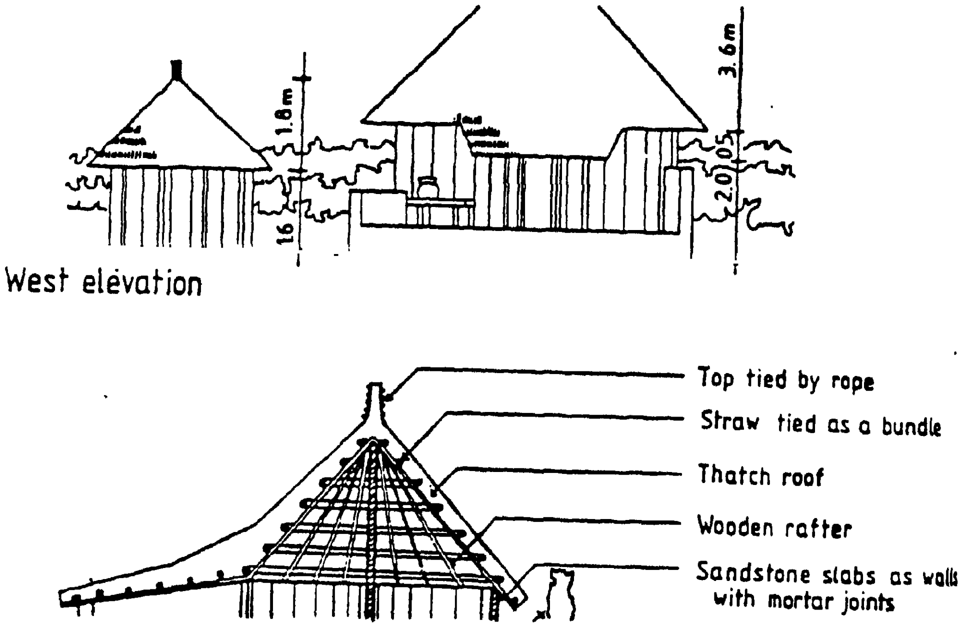

Fig. 2: Passive features for hot and dry climate.

- Reduction of solar heat gain
  - by small surface-to-volume ratio, achieved by circular plan of house
  - by partial shading of walls, by overhanging eaves and fence (on the east side)
  - by avoiding openings other than the door
- Reduction of heat transmission to the interior
  - by thermally insulating thatch roof
  - by wind-breaker/fence for protection against hot winds
- Increase of heat loss

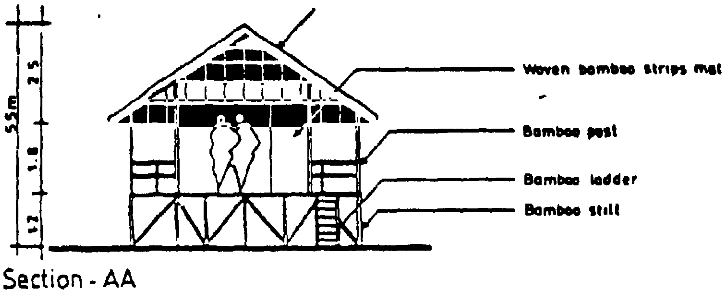

Fig. 3: Passive features for warm and humid climate.

- Reduction of solar heat gain
  - by roof overhang
- Reduction of internal heat gain
  - by locating the kitchen outside the house
- Increase of heat loss
  - by raising the structure on stilts
  - by ventilation through walls
  - by light roof

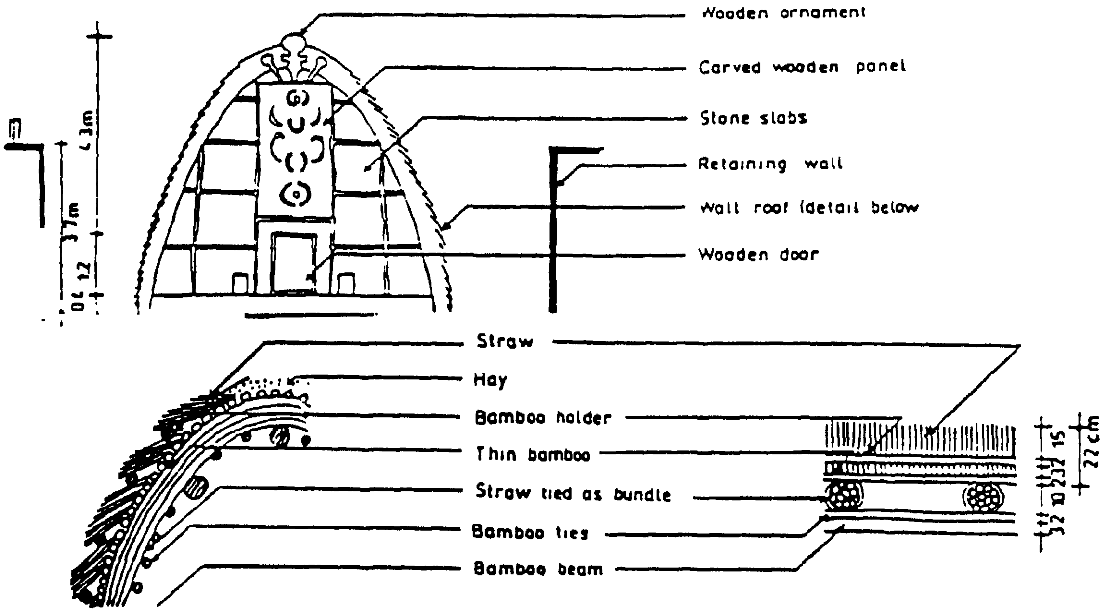

Fig. 4: Passive features for cold and cloudy climate.

- Decrease of heat loss
  - by high thermal insulation of walls and roof
  - by providing only small doors and openings to reduce air infiltration
  - by providing a wind-shaded pit
  - by providing a small exposed surface area in the form of a vault-shaped structure

With such construction, the interception of solar radiation is reduced and then the transmission of heat through the roof is minimized. Here too, the openings are very small to avoid heat-gain through hot winds during the day. The people also build wind barriers to reduce wind speeds. During the night time, people sleep outdoors.

In warm and humid climates along the coast, people build light houses with large openings to facilitate natural ventilation. The roofs are sloped for easy drainage of rainwater (Fig. 3).

In the cold and cloudy conditions of North-Eastern India, people build their huts in the form of an inverted catenary so that the loads are transfered to the foundation and the rain water drains off immediately (Fig. 4).

Even in the urban context, Rajasthani architecture shows characteristics of climatic conscious building design. Mutual shading, overhangs, orientation, courtyards, large surface areas for increasing radiation losses during the night and many other aspects are useful for increasing energy efficiency in buildings in the contemporary context.

The following concepts can be listed for heating, cooling and combined heating and cooling.

Concepts for Heating in Cold Regions

In cold regions where the inside spaces need heating, the first step is to use concepts of building design which result in reduction of heat losses. The use of thermal insulation, advance windows, building forms with low surface-to-volume ratio, reduced air infiltration and shelter from cold winds are a few concepts that help to reduce heat losses in buildings.

After an architect has conceived a design to reduce heat losses to the maximum possible, the next step is to increase solar heat gain in the buildings. Orientation of the building, particularly of windows, can play a major role in reducing heating energy demand in buildings. Of course the windows in this case have to be constructed with insulated glass or even advance glazing systems. The use of different glazing systems and transparent insulation has been one of the major technological advances in recent years. Many countries, like France and Holland, have introduced advance windows commercially with governmental support.

Passive heating techniques, like a thermal storage wall, Trombe wall, attached greenhouse, etc. have been used in many buildings all around the world with positive results. The performance of each of these passive concepts depends upon the climate and the type of building and the architects have to understand each of them in this context before applying them in a building design.

Concepts for Cooling in Hot Climatic Conditions

For achieving natural cooling for buildings in hot climates, there are basically three principles that have to be used intelligently by the architect.

1. Reduce the solar radiation that reaches the building envelope;
2. Reduce the heat transmission through the building envelope;
3. Increase heat losses from the building by convection, radiation and evaporation.

In order to reduce the amount of solar radiation that reaches the building, the natural way is to use the shade of neighbouring buildings and vegetation, to provide overhangs and louvres and even use reflecting surfaces wherever possible (taking care to avoid causing glare). Sometimes a boundary of shrubs or trees around the house is very useful to effectively reduce the speed and even the temperature of the incoming hot winds.

After the designer has done his best to reduce the interception of solar radiation, the next natural step is to reduce the heat transmission into the building. In this context the use of air cavities and thermal insulation is very well known. However, one has started thinking of using ventilated cavities which can provide for removal of the transmitted heat more effectively. Such cavities were built in a few old buildings at Jaisalmer, but their effect has not been quantified yet, particularly for the cooling.

Once the heat has been transmitted into the building, it has to be removed and discharged to the outside. The most natural way to remove heat is by ventilation. The arrangement of windows again plays a vital role in this regard. The use of courtyards is an effective way to discharge heat and to create natural ventilation and is common practice in many countries. Additionally, wind towers and air vents have been used effectively in Persian architecture.

It is a well known fact that the temperature of the earth a few meters below the surface is constant and normally equal to the annual average temperature of the ambient air. It is due to this that cellars are cooler in summer and warmer in winter. Building underground has been one of the traditional ways of protection from the scorching heat. Additionaly, an underground tunnel can be used to cool the ambient air. The ambient air is drawn into this tunnel and the cooled air is then discharged into the building. Efforts are going on to optimize this system, especially in Germany.

The thermal capacity of the building material results in a delay of the entry of heat and in'red icing the temperature amplitude (difference between maximum and minimum temperature). The thermal storage effect increases with increasing compactness, density and specific heat of the materials. This is the reason why the temperature of the ocean fluctuates over only a small range during the year.

whereas a thin metal sheet immediately assumes the temperature of the ambient air. All building elements, such as walls, roof and floor can be used for thermal storage. In order to dampen the effect of diurnal variations in the exterior environment and thus maintain the internal temperature at a relatively constant value, a heavy wall is used. This wall can store heat and has the ability to resist heat flow. The most effective way of maximizing these two properties in a building is to use a combination of material with a large thermal capacity (concrete, brick etc.) and a material with low thermal capacity but with high resistance to heat flow (such as expanded polystyrene). Insulation is an ideal way to reduce the effect of diurnal temperature fluctuations.

In hot and dry climatic conditions, evaporation of water is a very effective way of cooling the outdoors as well as indoor. These concepts have been used very effectively in the past as well as in contemporary architecture.

Concepts for Both Heating and Cooling

In mixed climatic conditions, where cooling in summer and heating in winter is needed, the concepts of both heating and cooling are relevant. The building, however, has to be heavy to balance the temperature fluctuations. Overhangs and louvres should be provided intelligently to shade the building in summer and yet allow exposure to the winter sun.

Conclusion

The concepts, design patterns and materials used in the traditional architecture in India and elsewhere in the world have become more relevant in the present time because of extreme pressure on infrastructure, particularly energy and environment. An architect, though aware of their use, finds it difficult to size and quantify them in designing a building in the absence of proper tools. The result, therefore, is that such buildings perform much below their expected performance. There is an urgent need to provide tools to quantify and size many of these concepts. The tools need to be simple and easily useable by a building architect/designer.

Building Energy Requirements in Different Climatic Zones of India

N. K. BANSAL

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1. Introduction

Electricity consumption in buildings is approximately twenty five per cent of the total consumption in the country. The distribution for various uses differs for commercial and residential buildings (Fig. 1). It is a well known fact that during peak summer and winter periods, the gap between demand and supply of power increases due to heavy demands of cooling or heating energy. In modern Indian buildings, which are air-conditioned, the specific energy consumption is rather high. In western countries, efforts are being made to bring down the annual energy consumption to the level of 50 $\mathrm{kWh/m^2a}$. Such drastic reductions are possible only through a series of measures in the building design, selection of building materials and building components and also through the choice of the system apart from methods like controls and users' aspects. In this paper we essentially concentrate on the design and material aspects and quantify the possible energy savings in different climatic conditions prevailing in the country.

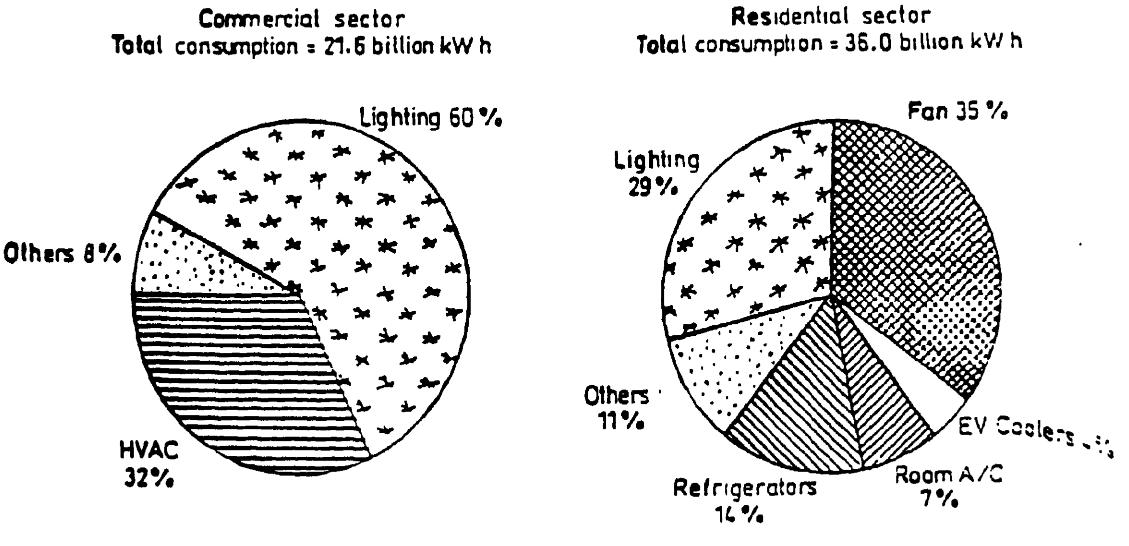


Fig. 1: Energy consumption by buildings in India.

2. Climatic Zones

India possesses a large variety of climates ranging from extremely hot desert regions to high altitude locations with severe cold conditions. On the basis of monthly mean data recorded at 233 stations, located in all parts of India, it was found convenient to divide the country into six climatic zones (Fig. 2). The representative locations chosen for studying the effect of efficient windows are Leh (Cold and Sunny), Shillong (Cold and Cloudy), Delhi (Composite), Jodhpur (Hot and Dry), Madras (Warm and Humid) and Bangalore (Moderate). The numbers of degree-days for each of these representative locations (with set point temperature of 20 °C) are given in Table 1.

Energy gains/losses take place through windows, walls, roof and floor and in addition ventilation losses contribute to the energy consumption for heating/cooling especially in an air-conditioned building. A typical distribution of annual energy demand (thermal) for cooling for a 100 m^2 floor area building in Delhi type of mixed climatic conditions is given in Fig. 3. There are a number of passive means which may result in reduced energy consumptions. The exact amount will vary from building to building, but some estimates due to these measures are given in Table 2.

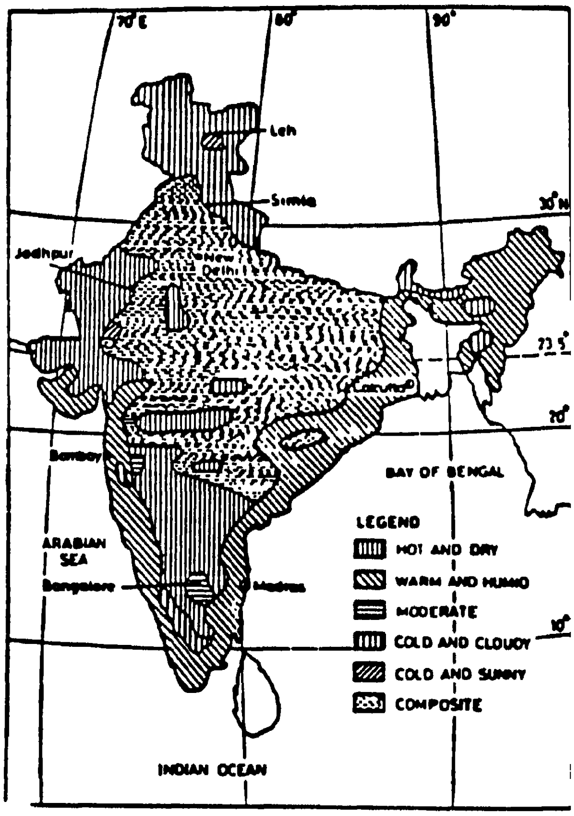


Fig. 2: Climatic zones of India.

Table 1: Degree days for representative locations of different climatic zones in India (set point temperature = 20°C)

	Leh	*Shillong*	*Delhi*	*Jodhpur*	*Madras*	*Bangalore*
January	880	326	178	93	140*	0
February	714	232	90	0	163*	87*
March	620	124	81*	161*	245*	174*
April	432	33	258*	310*	312*	219*
May	313	12	419*	447*	394*	214*
June	183	0	430*	429*	372*	129*
July	81	0	430*	429*	372*	129*
August	81	0	347*	316*	332*	100*
September	207	0	279*	282*	290*	100*
October	415	84	183*	236*	251*	100*
November	582	201	0	78*	174*	51*
December	766	298	133	421	143*	0

* Cooling degree days.

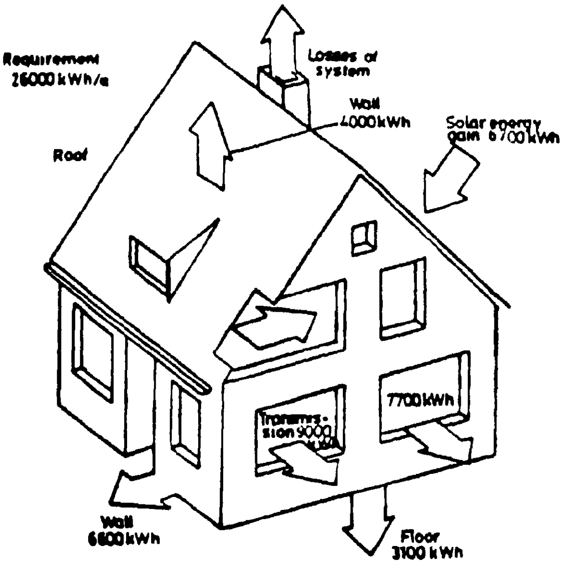


Fig. 3: Annual energy demand in a building of 100 m^2 plinth area (Delhi).

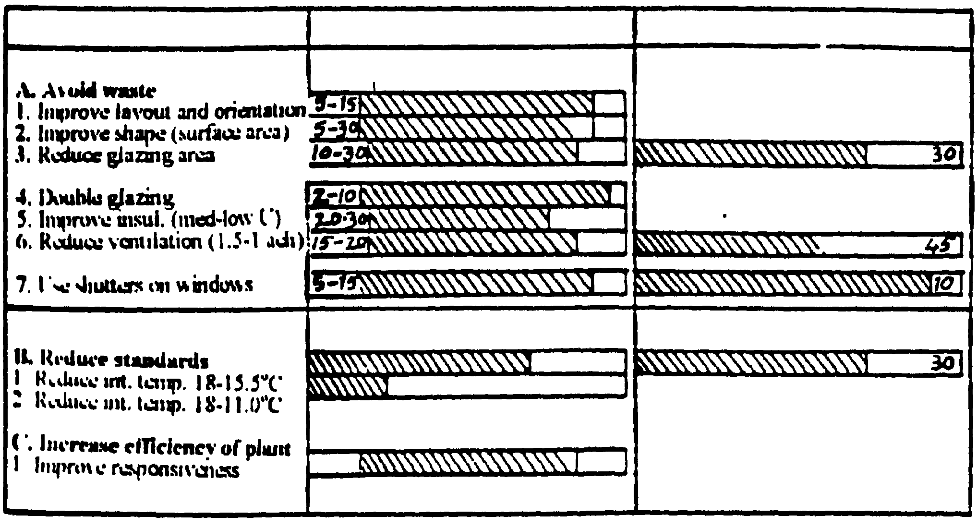
Insulation in walls and roof along with sealed insulated glazed windows reduce the peak load and annual energy consumption very significantly. Another important characteristic that determines the peak load is the thermal capacity or the storage capability. A building with thermal capacity has inertial effects resulting in time lag and reduction of peak heating and cooling load (Fig. 4), thus reducing the capacity of heating or cooling equipment.

In addition to building design and construction details, the energy consumption in a building is influenced by weather parameters such as ambient temperature, sky conditions, rainfall, solar radiation etc. However, out of these parameters ambient temperature and solar radiation are most important. The evaluation of solar radiation on building façades has been the subject of considerable scientific and practical work. However, it is possible now to predict the amount of solar radiation incident on various façades with reasonable accuracy. The effect of energy consumption in buildings can be accurately evaluated only by thermal simulation programmes.

3. Base Case: Single Zone Building

To simulate the effect of different measures in the building envelope to reduce the peak heating/cooling load as well as the annual energy, we consider a single zone building (Fig. 5)

Table 2: Percentage change of various aspects in energy consumption in buildings



A. Avoid waste		
1. Improve layout and orientation	5-15	
2. Improve shape (surface area)	5-30	
3. Reduce glazing area	10-30	30
4. Double glazing	2-10	
5. Improve insul. (med-low C)	20-30	
6. Reduce ventilation (1.5-1 ach)	15-20	45
7. Use shutters on windows	5-15	10
B. Reduce standards		
1 Reduce int. temp. 18-15.5°C		30
2 Reduce int. temp. 18-11.0°C		
C. Increase efficiency of plant		
1 Improve responsiveness		

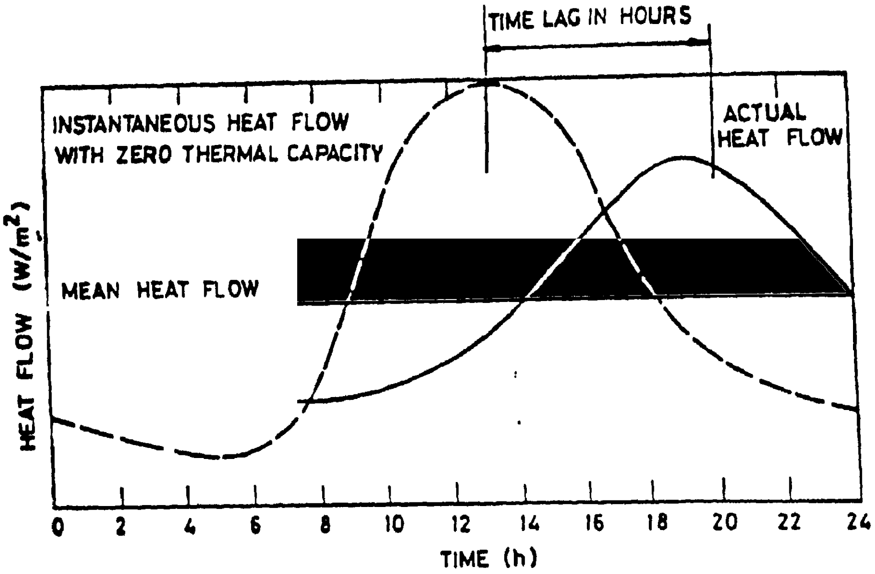


Fig. 4: Heat flow rate in buildings with and without thermal capacity.

Table 3: Specific energy consumption (normalized to floor area) (kWh/m^{2}a)

	Single glazing	*Double glazing*	*% gain*
Leh (CS)	550	446	19%
Shillong (CC)	136	110	19%
Delhi (CO)	240	194	19%
Jodhpur (HD)	265	215	19%
Madras (WH)	325	264	19%
Bangalore (MO)	133	108	19%

with single and double glazed windows in the south oriented wall and occupying 15% of the wall area. The specific energy consumption using the degree day method corresponding to various climatic conditions is given in Table 2.

It is evident from the table that the saving by using double glazed windows is the same (19%) in all the climatic conditions, the reason being that this method does not take the capacity and the dynamic behaviour of the building into account. The dynamic simulation

Table 4: Expected load reduction through different energy saving measures in different climatic conditions

Case No	*Cases*	*Annual Cooling/Heating Energy Demand (kWh)*					
		Delhi (CO)	*Jodhpur (HD)*	*Bombay (WH)*	*Bangalore (MO)*	*Simla* (CC)*	*Leh* (CS)*
1	Base case [brick wall, RCC roof, south window (20% floor area) ach=1, set pt=24]	3.763	3.831	2.998	2.086	2.229(set pt = 18)	5.392 (set pt = 18)
2	1 + double glazed windows	3.629	3.640	2.938	2.054	2.058	5.027
3	1 + cavity roof	3.278	3.393	2.568	1.781	1.993	4.963
4	3 + cavity walls	2.703	2.875	2.100	1.470	1.689	4.265
5	1 + roof insulation	2.504	2.751	1.866	1.392	1.703	4.329
6	1 + cavity walls + roof insulation	1.957	2.237	1.397	1.160	2.413	5.518
7	Case 1 but window is in north	3.778	3.834	3.010	2.061	2.413	5.518
8	Case 1 but ach = 3	3.949	4.196	3.069	2.241	2.353	5.638
9	1 + insulation on walls and roof	1.242	1.579	0.861	0.889	0.970	2.544
10	1 but set pt = 26 (16 for heating)	3.319	3.370	2.564	1.649	1.817	4.979

* Heating

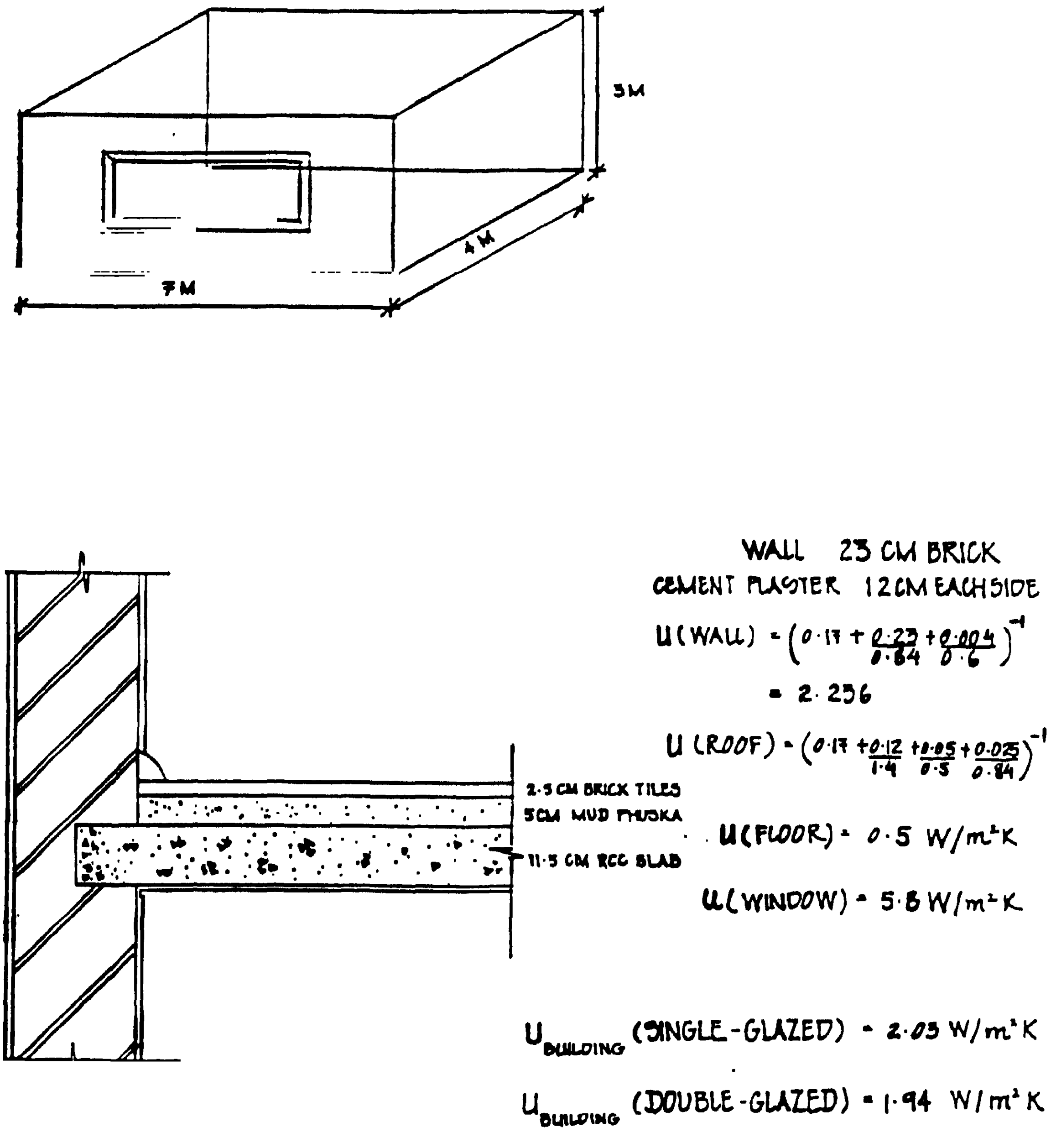

3M
4M
7M
WALL 23 CM BRICK
CEMENT PLASTER 12CM EACH SIDE
$U(\text{WALL}) = \left(0.17 + \frac{0.23}{0.84} + \frac{0.004}{0.6}\right)^{-1}$
$= 2.236$
$U(\text{ROOF}) = \left(0.17 + \frac{0.12}{1.4} + \frac{0.05}{0.5} + \frac{0.025}{0.84}\right)^{-1}$
2.5 CM BRICK TILES
5CM MUD PHUSKA
11.5 CM RCC SLAB
$U(\text{FLOOR}) = 0.5\ W/m^2K$
$U(\text{WINDOW}) = 5.8\ W/m^2K$
U_{BUILDING} (SINGLE-GLAZED) $= 2.05\ W/m^2K$
U_{BUILDING} (DOUBLE-GLAZED) $= 1.94\ W/m^2K$

Fig. 5: A simple, single zone building with normal construction used as an example.

model takes into account the storage effect that the building possesses. This effect is generally ignored in a/c load calculations and therefore higher capacities of air conditioning systems are proposed.

The building has been simulated by using a sophisticated dynamic simulation model DOE 2.1 E. The total peak load comes out to be 3.763 kW for cooling with component-wise contribution given in Fig. 6 alongwith the energy consumption also. The figure corresponds to Delhi type of mixed climatic conditions where no occupancy, no equipment and no lighting has been considered. From the figure it is clear that there is a vast potential of energy saving by using suitable wall and roof elements. In an office building, however, the equipment (about 300 VA per person) also

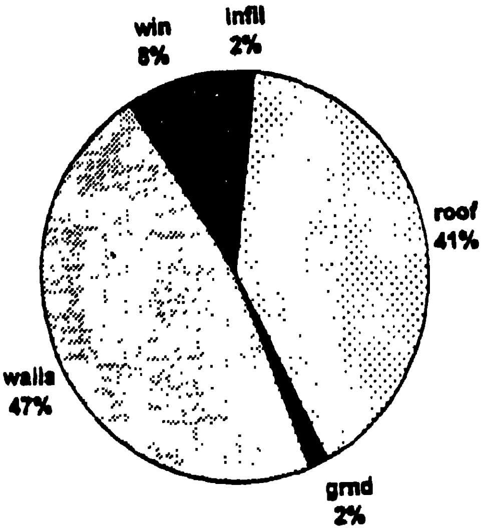


Fig. 6a: Peak load = 3.763 kW.

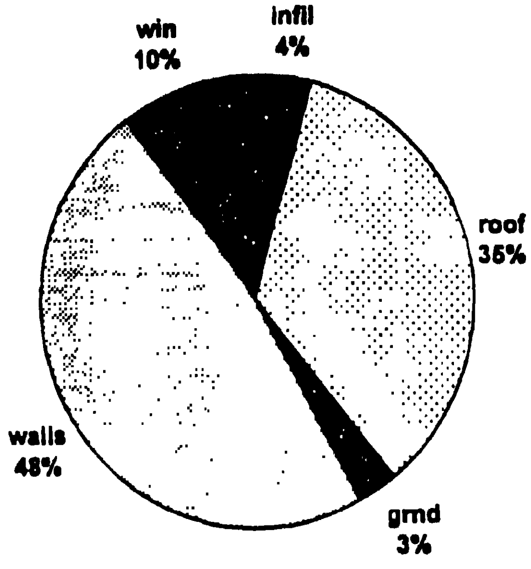


Fig. 6b: Annual energy = 12777 kWh.

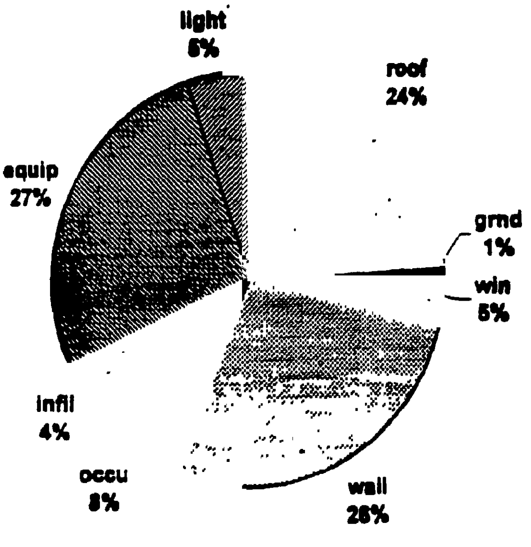


Fig. 7a: Peak load = 6.592 kW.

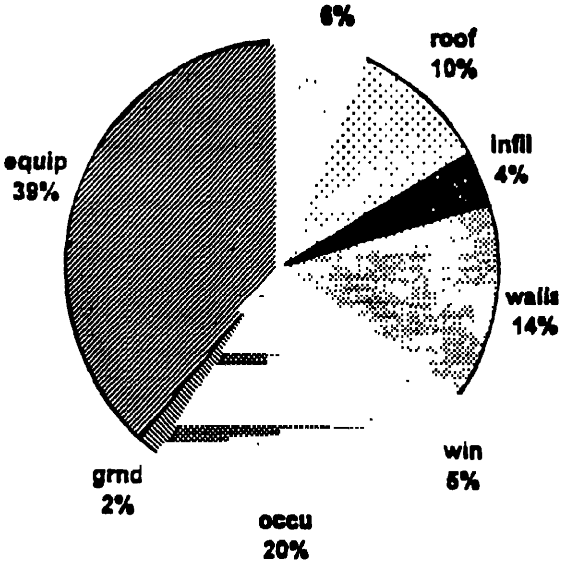


Fig. 7b: Annual energy = 38652 kWh.

contributes significantly by increasing the cooling load and the annual energy consumption (Fig. 7). The relative importance of windows in this case is much less. Roofs and walls which can resist heat and the energy efficient equipment, can substantially lower the peak load and annual energy consumption at least for cooling.

From the point of view of building design, however, we have concentrated on a building which is not occupied and simulated it for different climatic zones and for different varia-

Table 5: Specific energy consumption and percentage savings by energy conserving measures in different climatic conditions (Figures in parentheses show the percentage reduction)

Case No	*Cases*	*Annual Cooling/Heating Energy Demand (kWh/m^{2}a)*					
		Delhi (CO)	*Jodhpur (HD)*	*Bombay (WH)*	*Bangalore (MO)*	*Simla* (CC)*	*Leh* (CS)*
1	Base case	440.82 (–)	485.46 (–)	489.39 (–)	178.46 (–)	119.86 (–)	674.29 (–)
2	1 + double glazed windows	431.43 (2.1)	469.43 (3.3)	480.64 (1.8)	183.07 (-2.6)	104.96 (12.4)	617.75 (8.4)
3	1 + cavity roof	392.68 (10.9)	442.18 (8.9)	435.43 (11.0)	150.43 (15.7)	109.71 (8.5)	635.43 (5.8)
4	3 + cavity walls	326.39 (26.0)	376.61 (22.4)	363.71 (25.7)	124.96 (30.0)	96.79 (19.2)	566.79 (15.9)
5	1 + roof insulation	310.46 (29.6)	370.00 (23.8)	339.75 (30.6)	104.32 (41.5)	98.61 (17.7)	579.64 (14.0)
6	1 + cavity walls + roof insulation	244.82 (44.5)	304.96 (37.2)	268.07 (45.2)	79.64 (55.4)	86.61 (27.7)	515.32 (23.6)
7	Case 1 but window is in north	432.36 (1.9)	473.54 (2.5)	478.89 (2.1)	172.11 (3.6)	137.39 (–14.6)	686.89 (–1.9)
8	Case 1 but ach = 3	452.7 (–2.7)	516.21 (–6.3)	499.71 (–2.1)	179.04 (–0.3)	131.14 (–9.4)	720.11 (–6.8)
9	1 + insulation on walls and roof	145.71 (–2.7)	204.57 (57.9)	153.04 (68.7)	51.39 (71.2)	60.96 (49.1)	398.54 (40.9)
10	1 but set pt = 26 (16 for heating)	343.61 (22.1)	377.71 (22.2)	360.82 (26.3)	90.43 (49.3)	73.68 (38.5)	574.29 (14.8)

* Heating

tions of roof, wall construction, windows and also computed the effect of raising the set point temperature of the a/c equipment from 24 °C to 26 °C for cooling and from 20 °C to 16 °C for heating purposes. The peak load for cooling and heating at different locations, which represent various climatic zones are given in Table 4 and the corresponding specific energy consumption rationalized in terms of kWh per sq. m of floor area are given in Table 5. Some of the observations that are important from the point of view of energy efficiency through building designs are:

1. Double glazed windows are much more effective in cold climatic conditions where heating is required.
2. A cavity in roof and walls can reduce the peak load between 20% to 29%. In extreme climates, a cavity is less effective.
3. Provision of insulation in walls and roof (about 5 cm of glass wool) can reduce the load between 50% to 67%. For cooling requirements, the effect of insulation is more.

Tolerating higher or cooler temperatures in summer and winter respectively (26°C instead of 24°C and 16°C instead of 20°C) can save energy consumption between 15 to 22%.

4. Conclusions

The results presented in this paper for a single zone building with 20% windows towards the south for peak load and specific energy consumption are illustrative but conclusive in the sense that buildings which are kept at nearly constant temperature by using heating or cooling devices need to be insulated for saving on the capacity of the heating/cooling machine as well as on the annual energy consumption. In cold climates, the windows should preferably be sealed and double glazed. In multi-storeyed buildings, the effect of windows could be much more than for the simplified version presented in this paper. Provision of a cavity itself can reduce energy consumption by at least 20%. The architects should keep this in mind while designing roof and wall details. In non-conditioned buildings also, these measures will help in better comfort conditions.

One point needs to be stressed very strongly. This is, that our conditioned buildings are very energy intensive in comparison to buildings in the west. In the west, specific energy consumption is about 100 kWh/m^{2}a and in contrast we consume about 400 kWh/m^{2}a in terms of primary energy. We need to check this extravagance.

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An initiative for energy efficient buildings

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Abstract

The importance of energy conservation and increasing use of renewable sources of energy in the transition to a sustainable development has already been recognized in the country. During the past quarter of a century, a significant thrust has been given to the development, trial and inclusion of a variety of technologies which can meet our energy needs on a sustainable basis and are environmentally acceptable. This paper presents one such initiative by the Ministry of Non-Conventional Energy Sources.

Key words: Solar passive architecture, energy efficiency, low energy materials, renewable energy technologies

Introduction

The building sector in our country is one of the largest energy consuming sectors. In modern buildings significant amount of energy is consumed to keep the built environment comfortable. Energy consumption for production of building materials and construction of buildings is also significant. The purpose of constructing a building is to provide a shelter- an artificial environment which is more conducive for human occupancy than the natural environment. It is expected to be aesthetically appealing. Modern architecture with its many significant achievements is, however, more inclined to energy intensive solutions to achieve these objectives.

Like any other developing economy, in India also, with increasing standards of living, the energy consumption in the building sector has been progressively increasing. As population grow and become more urbanized, there would be increasing activities in the building sector for construction and also for adequate arrangements for comfort of the built environment. This would demand larger share of energy in an already strained energy supply scenario of the country.

Since the required energy is mainly derived from fossil fuels, the building sector has become a major perturbing factor to the environment. The energy related perturbation is contributed by green house gas (GHG) emissions and emissions of acid rain precursors like sulpher dioxides and nitrogen oxides. Air-conditioning and refrigeration contributes to emissions of ozone depleting substances (ODS). The environmental impact resulting from the energy consumption in the building sector has, of late, become a global concern.

In this scenario introduction of energy efficient building design concept has become critical to achieving the collective objectives of energy security and environmental protection which in turn can ensure economic and social development.

Energy Efficient Building Design Concept

Energy efficient building design is essentially an integrated approach. The available options in architectural intervention, building materials, available technologies and design methodologies are required to be carefully evaluated to minimize energy usage and provide cost effective solutions. The purpose is to achieve total comfort with the least amount of conventional energy input. This would save scarce fossil resources and result in concomitant environmental benefits. Not only the new building stock can be targeted but also retrofitting of the existing buildings with newer technologies can result reduction of energy consumption in large number of cases. The various options, which are available for achieving the above objectives, are as follows:

Solar passive techniques

Passive solar techniques capture adequate solar energy for heating the building during the winter and provide for shading from the sun during the summer. The initial approach is to provide a suitable orientation with respect to the sun. Vegetation, overhangs, awnings or sunscreen accomplishes optimum solar designs. To reject heat in a hot climate, natural sinks are used and ventilation wherever required is maximized. The useful daylight is harnessed through appropriate windows and skylights and more recently through light shelves.

Many of the solar passive techniques based on traditional wisdom date back to ancient times. Over hundreds of years in various geographical regions of the world, many of these techniques have progressively got refined. This traditional architectural concept offers a more comfortable built environment compared to conventional structures. With recent advances in computational aids , more accurate and site specific designs are now possible. As a result of efforts made in many countries of the world including ours to promote this technology, a host of new techniques and materials (advanced glazings, storage materials, light pipes, fibre optics etc.) are now available expanding the opportunities for wider applications of the technology.

Energy efficiency

Increasing insulation levels in conditioned buildings is regarded as the most cost-effective investment in energy efficiency. Thermal insulation of external walls, roof and floor and double pane windows can reduce energy consumption for space heating by lowering heat losses through the envelope of the building. Energy consumption for cooling can also get reduced because of lesser heat gains from outside through the envelope.

For cold climate a newer development is *'transparent insulation material'* (TIM). As the name suggests TIMs are characterized by their ability to transmit solar radiation while providing sufficient insulation against heat losses.

Air conditioning (AC) and refrigeration technology is undergoing major changes because of increasing environmental consciousness and decreasing energy availability. The change is towards higher efficiency and better environmental acceptability. Efficient AC system and strategic energy conservation measures must be adopted to reduce energy consumption of a building due to cooling. Solar cooling systems based on vapour absorption refrigeration, though technically feasible has so far failed to achieve economic competitiveness. Further R&D is in progress.

Energy efficient lights consume considerably less electricity than an incandescent lamp for producing the same light. Its cost is high but lasts for longer duration and the running cost is less. Such lamps are now available in variety of wattages. As electricity is efficiently being converted to light in these energy efficient lamps, the amount of heat generated is significantly less.

Solar Buildings Programme of MNES

The concern for energy scarcity and the environmental problems associated with consumption of energy in the building sector have resulted in continued interest in energy efficient building design. For about two decades, the Ministry of Non-Conventional Energy Sources (MNES) has been working on the possibility of using solar energy in the building sector for reducing energy consumption in buildings through climate responsive designs and providing clean renewable energy sources to meet part of the energy loads of buildings. Since 1994 through a comprehensive Solar Passive Architecture Programme, MNES has undertaken several activities to promote energy efficient building design concept in the country. The programme is currently known as the Solar Buildings Programme .

The primary objective of the Solar Buildings Programme is to promote energy efficient building designs through optimum use of available solar energy and other forms of ambient energy in building energy management. The programme has several components namely Research & Development, Training & Education, Awareness creation and Demonstration [4].

Research & development

R&D projects are sponsored by the Ministry at universities, national laboratories and other research institutions with the objective of developing suitable design techniques and concepts, software packages, architectural instruments, materials, thumb rules etc. for solar efficient buildings.

An important requirement for designing an energy efficient building is to have adequate knowledge of the climatic conditions of the given location. In order to provide this information to the building designers, through a sponsored research project, the information on climatic parameters collected by the meteorological stations of the India Meteorological Department (IMD) over the years was analysed and presented in a concise form. In the study, on the basis of monthly mean data recorded in 233 stations located in different parts of India, the country has been classified into six climatic zones[5]. This classification has further been used to evolve suitable design guidelines for buildings in different climatic zones [6]. Computer softwares have also been developed to help designing a building in harmony with the nature and in the process to make it a low energy building by optimizing use of the available solar and other ambient forms of energy.

Through another sponsored project ambient design conditions have been developed for 52 stations in India as per ASHRAE (1997) format [7]. Weather database for different climatic regions in the country have also been developed in standard formats acceptable to most applications.

Training & education

Under this programme workshops and seminars are being organized throughout the country for creating awareness, generating public interest and providing inputs about the technology to engineers, academicians, scientists, planners, builders, students and potential house owners. Orientation courses are regularly being organized for architects to make them familiar with the new developments and to motivate them for adopting solar efficient building design concepts.

Training & education is one of the major actions to disseminate the available knowledge on the subject. Since the inception of the programme, more than 70 such training programmes have been organized in different parts of the country. Every year around 10 such programmes are targeted. The programmes include both One-day Workshops and Seminars and Orientation Courses of 3-5 days duration. These programmes are normally being organized by research institutes, *Energy efficient glazings (insulating glasses, solar controlled glazings, low-e glazings etc.)* can contribute for efficient utilization of energy in three ways- by reducing the capacity of installed air conditioning system, by lowering the electricity consumption for its operation and by reducing the electricity consumption due to lighting by the optimal use of natural daylight in buildings which are used during daytime.

The above mentioned energy management techniques are often more cost effective in providing a given level of energy services than any energy supply strategy [1]. Specifications of the glazings, however, are required to be defined and matched to the particular requirements and environmental strategy of each building.

Renewable energy technologies

Solar water heaters currently available in the market can generate hot water at 60-80 C and can conveniently be used for building requirements. The technology is fairly mature and economically viable. It can affect considerable saving of electricity. The technology has already found success in market penetration in western and southern parts of the country.

Solar air heaters can supplement heating requirement of a building during daytime. In cold and sunny climate, these can be used extensively to reduce demand of electricity and firewood for space heating. Old buildings can also be retrofitted with solar air panels very easily.

Solar electricity can be generated by integrating solar cells in buildings, on roofs and facades, or by installing grid connected photovoltaic (PV) power plants. It is an expensive proposition where grid connected electricity is available. However, for locations where conventional electricity is not available or the grid is far away, it makes an ideal alternative [2]. PV power plant offers a number of advantages compared to conventional electricity. It provides the energy security. Inclined roofs if oriented in the right direction, for instance, are an ideal support structure for PV modules, and construction costs can be minimized. Grid connected plants offers the possibility of supplying surplus amounts of PV electricity to the national grid.

Low energy materials and methods for building construction

An analysis of the 'embodied energy' of a range of different building materials, construction methodologies and building type suggests that the energy requirement for constructing a building can represent many times the energy used by the building in a single year of operation [3]. For an energy efficient structure, it is therefore necessary to closely examine the issue of building materials and to take an appropriate decision. The rules for decision making for selecting materials for construction in an energy efficient way as suggested by Robert Vale [3] are given in Table 1.

Table 1: Selecting materials for construction

Rules for Decision Making

- Where two materials exist that will perform the same function for the same price, choose the less toxic of the two
- Wherever practicable choose materials that are unrefined and as close as possible to their natural state
- Use local materials wherever possible, the heaviest materials should be obtained from the closest sources
- Design for minimum energy consumption and maximum longevity

universities, colleges of architecture, engineering colleges, state nodal agencies, and other professional organizations. Necessary financial support for organizing these programmes/courses is provided by the Ministry. Some of these programmes are general in nature and some are focussed. While the programmes with general contents impart basic understanding, highlight benefits and enthuse the general public, the more focussed programmes help educating a group of professionals and also the knowledge base in the area is crystallized [8].

One of the objectives of this programme is also to develop a suitable curriculum to be introduced in the schools of architecture.

Demonstration

To demonstrate the concept of solar buildings, the Ministry is promoting design and construction of solar buildings in government and semi government sectors. Under the Demonstration Programme a number of energy efficient buildings have already been constructed. A list of these buildings is given in Table 2. A number of other buildings are in the process of design. The energy requirement of a specific building depends on the type of building (residential, commercial institutional), microclimate of the building site, building material & construction, annual hours of use, requirement of hot water and installations for heating, cooling and lighting. In these demonstration buildings, constructed in different climatic zones of the country, an energy efficient approach has been adopted to meet the above requirements wherever possible.

Table 2: MNES supported Energy Efficient Buildings

Cold & Cloudy Climate	**Composite Climate**
• State Bank of Patiala, Shimla	• Urja Bhavan, Bhopal
• Minister's residence, Shimla	• School of Energy & Environmental Studies, DAV,
• Judges' Houses, Shimla	Indore
• MLA Hostel, Shimla	•Solar Energy Centre, Gwalpahari
• 200 Bed Hospital at Khaneri	• RETREAT Building, TERI, Gwalpahari
• HP Cooperative Bank, Shimla	• PEDA building, Chandigarh (under construction)
• Nirman Bhavan Shimla	**Warm & Humid Climate**
• Himurja building, Shimla	• WBREDA Building, Calcutta
• Nirman Bhavan, Shimla (under construction)	**Hot & Dry Climate**
• HPWD Rest house, Kotgarh (under construction)	• Solar Passive Hostel, Jodhpur

An important outcome of the demonstration projects is development of a group of experienced architects and consultants in the area. These personnel would utilize their experience in many other projects they would be associated with subsequently. The multiplier effect has already been observed. A number of energy efficient buildings have already been constructed in the country through private initiatives[9].

Awareness creation

Awareness programme envisages creating awareness about the technology through popular literatures, publication of books for architects and engineers, publicity through various media etc. Under this programme the Ministry has brought out various publications (Table 3).

Table 3: Publications on Energy Efficient Buildings

- *Climatic zones and rural housing in India
- * Passive building design - a handbook of natural climatic control
- * Energy efficient lighting & day lighting in buildings
- * Weather data & design conditions for India
- * Manual on solar passive architecture
- * Energy efficient buildings in India
- * Representative designs of energy efficient buildings in India

Planned

- *A special issue of Urja Bharati on solar architecture
- *Energy efficient windows
- *A manual on earth air tunnel

Promotional Incentives

To encourage various government and semi government organizations for constructing their new buildings on the basis of solar design principles, the Ministry provides partial financial assistance to the extent of 50% (upto a maximum of Rs.50000), for preparation of Detailed Project Reports (DPRs) of such buildings and also 10% of the cost of construction (up to a maximum of Rs.1000000) of the buildings in government and semi government sector only.

The Ministry has also been implementing a soft loan programme for solar water heaters under which loans at reduced interest rates are available to the customers from IREDA and seven designated public sector banks (Canara Bank, Union Bank of India, Bank of Maharashtra, Syndicate Bank, Punjab National Bank, Punjab & Sind Bank & Andhra Bank).

The Karnataka State Electricity Board (KSEB) had introduced a rebate of 5 paise per unit in electricity tariff for homes using solar water heaters (SWHs) in 1997. The rebate has been increased to 15 paise from 2000. The Rajasthan State Electricity Board (RSEB) has similarly introduced a rebate of 5 paise per unit in the electricity tariff for consumers of domestic category who are using solar water heaters(2000).

Regulatory Measures

Based on the progress made in the development of technologies related to energy efficiency in the building sector, the central and a few state governments have initiated the following regulatory measures for wider applications of these technologies:

- All buildings in the Government sector in HP situated above 2000 metres to incorporate features of solar passive technology in their designs (2000)
- A model draft for making SWHs mandatory in several categories of buildings including residential buildings having more than150 sq. m plinth area have been formulated and circulated to all State Government for modifying building bye laws (1999).
- The Government of Rajasthan has made SWHs mandatory in various functional buildings including residential plots of more than 500 sq.m. area (2000)
- The states of AP, Haryana, HP, MP, Punjab, Rajasthan and UT of D&NH have made SWHs mandatory in state sector buildings.

Conclusion

From the above discussions, it is evident that the activities undertaken so far could create to some extent awareness regarding energy efficiency in the building sector. With increasing number of buildings being designed constructed and used, new information is continuously being generated. Performance evaluation of a few such buildings in various climatic locations has also been undertaken. The sector is a promising one and is expected to be developed further in a faster rate with the cooperation of architects, engineers, consultants and policy makers.

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Note: The paper essentially presents the Solar Buildings Programme of the Ministry and attempts an analysis of the same. However, the opinions expressed by the author in this paper are those of the author in his individual capacity and do not necessarily reflect the views of the Ministry

Energy efficient windows for reduction of air conditioning loads in buildings

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Abstract

Modern buildings with their air conditioning and elaborate lighting systems are immensely energy intensive. Such buildings are also responsible for peak load demand in urban conglomerates. It is possible to reduce electrical load of such buildings and achieve energy efficiency through judicious design of HVAC and lighting systems. In recent years, an array of energy efficient window technologies has emerged which can reduce the air conditioning load of the buildings, save electricity and minimize environmental pollution. In this paper, various types of energy efficient glazings, their potential for AC load reduction, environmental impact and economics have been discussed.

Key words: Air-conditioned buildings, Energy efficient windows, Electricity saving, Environmental emissions, Demand side management

Introduction

Air-conditioning is a major electricity end use. In India, it is progressively registering a larger share in electricity consumption because of a steady growth of the sector. Apart from high consumption of electricity, it adds substantially to the utility peak load and has already become a cause of concern for load management in urban conglomerates. Further growth of the sector will have significant effect on the power situation of the country.

Air-conditioned (AC) buildings in India are much more energy intensive compared to the buildings in industrialized countries. One of the main reasons of this inefficiency is large heat gains/losses through the windows and other glazed areas of the buildings. As in other parts of the world, in India also there has been a steady increase in glass-to-opaque wall ratio especially in commercial and institutional buildings. Though extended glazed openings are expected to provide natural daylighting but ordinary glazing systems with their energetically inappropriate use have only necessitated in high AC loads and resulted in higher electricity consumption.

Energy efficient windows (EEWs) with their high thermal insulating values and spectral selectivity can make the air-conditioning systems work more effectively. This can lead to reduction in AC loads, lower consumption of electrical energy and reduction in peak load demand (Bandyopahdyay, 2001).

Windows

Windows are architectural requirements of a building and have to perform various functions that include:

- View and visual contact with the outside world
- Sufficient day light
- Natural ventilation
- Direct sun in the winter.
- Aesthetics.

The magnitude of these functions varies in accordance with the climatic conditions. The successful design of a window depends on the optimization of one function against the other. The type of the building, its utilization pattern, the microclimate of the site, the traditions and the social or cultural environment in which the building exists influence the above criteria. The budget for the construction of the building is another overriding parameter for consideration (Bandyopadhyay, 1994).

In our country in an AC building, to minimize unwanted heat gains and losses through windows and also to avoid glare of daylight, normally some controlling devices are used. The traditional window control systems, which are often used, include:

- Interior shading devices such as shades, drapes, blinds etc.
- Fixed exterior shading devices such as overhangs, fins etc.
- Operable exterior sun control devices such as operable fins, louvers, shade systems etc.

These are primarily based on the need to provide comfort, privacy and aesthetics. Observed practices and some studies, however, suggest that operable options are rarely used in an energy efficient manner. These obstruct the outside view and do not allow the daylight to come in. As a result even during the day when sufficient solar light is available, artificial lights are used inside the AC buildings. The artificial lighting systems not only consume energy but also contribute to the cooling load of the building. The lights used in many such buildings are often not energy efficient.

We visualize a normal window as a frame made up of materials like wood, steel, aluminum or vinyl and covered with one or two glazings. A glazing is a transparent or translucent material used to cover the solar aperture. Conventional windows use clear glass as glazing. Sun is the principal source of heat and light for a building. The energy of the sun is received as the electromagnetic radiation with waves of varying lengths. Solar radiation, which is received on the earth, extends from 290 nm to 3000 nm. It can be broadly divided in three wavelength regions:

Ultraviolet Radiation (UV)	: 290 nm to 400 nm
Visible Light (VIS)	: 400 nm to 770 nm
Near Infrared radiation (NIR)	: 770 nm to 3000 nm

The energy contained in the UV and VIS region is around 47% and that of NIR region is 53% of the total solar energy received on the earth. Glasses are partially transparent (typically 80 to 85%) throughout the near ultraviolet, visible and near infrared regions that compose the solar spectrum; but are practically opaque to longer wave thermal radiation. The functional characteristics of a glazing are shown in Fig.1.

The following are the characteristic parameters that describe the basic functions of a glazing:

Visible transmission (T_v): The percentage of visible light (400-700 nm) that is transmitted through the glazing.

Solar heat gain factor (F): The portion of directly transmitted and absorbed solar energy that enters into the interior of the building.

Thermal transmittance (U): A measure of the rate of non-solar heat gain or loss through the glazing. It is expressed in units of Watt/Sq.m.C ($W/m^2 C$).

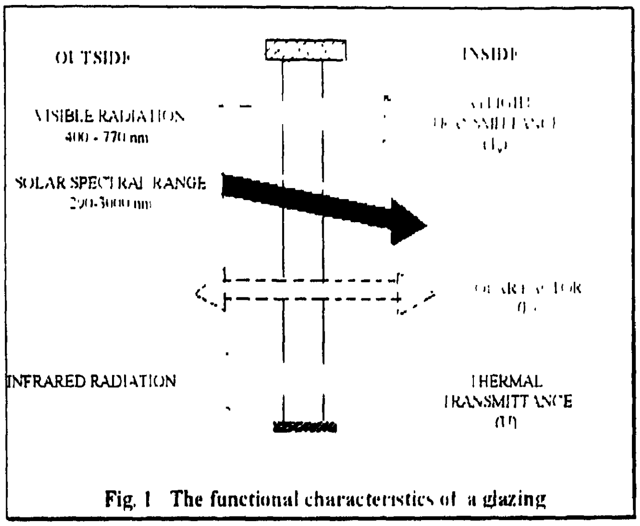

Fig. 1 The functional characteristics of a glazing

Energy efficient windows

Now a days, advanced glazings with innovative coatings and improved designs are available for energy conservation (Granqvist, 1991; Lampert 1989). These energy efficient glazings help minimizing unwanted solar gains in summer as well as heat losses in winter while maximizing the amount of useful daylight in buildings. As a result, these windows, when appropriately used, can provide thermal comfort and energy efficiency. The various types of advanced glazings, which are available today, are as follows:

Insulating Glasses:

Windows are available with multiple glazings separated by a desiccant filled spacer and sealed with an organic sealant. These windows provide a heat barrier through insulating air cavity between glass layers. Gases filled glazings with better thermal performance are also available.

Solar Control glazings:

The primary objective of these glazings is to control the entry of solar heat and light in the building. These are essentially non-selective metallic films that are deposited on glass or polymer substrates. Off late new material combination and coating processes have contributed in development of unique products. In these techniques, solar control is achieved either by absorptive process or by reflective process. The resultant glazings are available as heat absorbing glasses and heat reflecting glasses.

Low-emissivity glazings:

Energy and light control characteristics are uniquely demonstrated by Low-e (low emissivity) type of optical coatings. These optical coatings are normally applied to glass or plastic glazing materials and act as selective surfaces, which mean the radiative properties of these coatings are qualitatively different within different parts of the relevant electromagnetic spectrum. As a result, these glazings reduce heat gain or loss in a building by redirecting the heat. In addition these glazings offer greater light transmission, low reflection and reduce heat transfer.

Super windows

These are essentially combinations of insulating glasses and solar control coatings and/or low-e-coatings with appropriate frames. The super windows have low solar transmission and lower radiant heat transmission. These windows are expensive but offer an excellent opportunity for areas that experience unusual seasonal climatic variation.

Smart Windows

The properties of the glazings described above are static. But as both the heat and light conditions change continuously, it is desirable to have glazings with dynamic properties. This means that the glazings can automatically modify their properties in response to the outside conditions. As a result of continuous R&D prototype of electrochromic glazings are now available. These glazings can be switched from clear to reflective by changing the applied voltage in response to a control variable such as incident solar radiation. Such glazings have the potential of providing better solar control than the ones described above.

AC load reduction potential

A simple energy balance of a window system shows that the net heat flow per unit area (Q) through the glazing can be written as

$$Q = Q_s + Q_k \qquad (1)$$

Where Q_s is the solar heat gain and Q_k is the thermal gain due to temperature gradient between outside and inside of the building.

For a glazing system, a solar heat gain factor (F) is defined as the solar flux transmitted by a 3 mm clear glass plus the portion of the absorbed radiant flux that is transferred indoors.

$$F = T_e + q_i \qquad (2)$$

Where T_e is the solar transmittance and q_i is the secondary heat transfer co-efficient. For the usual clear window glass, the solar heat gain factor gives the solar heat gain directly when multiplied by the incident solar radiation (H). For fenestration other than standard clear glass solar heat gain is given by

$$Q_s = F \times SC \times H \qquad (3)$$

Shading co-efficient (SC) basically compares the solar control performance of different glazings. The shading co-efficient of a glazing is the ratio of solar heat gain through the glazing to the solar heat gain through a single layer of 3 mm clear sheet glass under the same set of conditions. From the definition, it is clear that the shading co-efficient is a unitless quantity, the value of which lies between 0 and 1. The lower the value of SC, the less solar heat it transmits. The reciprocal of shading co-efficient essentially gives the information about the extent of infrared and thermal shielding, which a particular solar control glazing can provide in comparison with a 3-mm clear sheet glass.

To take into account the composite effect of the visible transmittance and the shading co-efficient, a new parameter titled 'Coolness factor (k_e)' is now defined as the ratio of visible transmittance and the shading co-efficient.

$$k_e = T_v / SC \qquad (4)$$

If the coolness factor (k_e) is greater than 1, the glazing is considered to be 'selective' and would perform better in a hot climate than a similar glazing with a lower k_e.

As a generalized case, now we can write

$$Q = (T_e+q_i)\, SC \times H + U\,(T_o-T_i) \qquad (5)$$

Since air-conditioning is an energy intensive application, it is appropriate to use the concept of Total Equivalent Warming Impact (TEWI) to assess the environmental impact. TEWI is the sum of direct releases (refrigerant emissions) and indirect releases (CO_2 emissions for production of electricity required by the equipment during its lifetime). Through this concept energy efficiency of the equipment is taken into account. As discussed above, reduction of AC load and lesser consumption of electricity due to incorporating energy efficient windows in a building will reduce the green house gas emission to a great extent. Downsizing the capacity of the equipment will also require lesser amount of refrigerants.

From a detailed analysis of TEWI concept, it can be seen that incorporating energy efficiency in air conditioning systems through all possible means is a very important step to combat environmental pollution arising out of the air-conditioning equipment.

Economics

Energy efficient windows are widely used in countries of Europe, USA and Japan. As there is considerable production and demand, prices have come down to a reasonable level in these countries. However, as the availability of the product is still not widespread elsewhere, the cost may vary (Evan Mills, 1999). The investment for incorporating energy efficient windows in an air-conditioned building, in our country, therefore, may be considerably higher than ordinary windows.

The higher initial investment can be justified if the cumulative energy savings pay it back in a reasonable time period. Normally the 'pay-back-period' is calculated in number of years required for the sum of fuel savings to become equal to the cost of investment. The interest on the investment, and fuel cost escalation are taken into account. For a new building, the additional investment on energy efficient windows, however, can often be partially neutralized by the reduction of cost of the resultant downsized air conditioning loads. The pay back period then is expected to be very less. For a more accurate economic analysis, it is necessary to place a monetary value on other benefits accrued over the lifetime of this product. In this case, it is the environmental benefits discussed earlier. These benefits, if can be converted to monetary value, can be substantial.

Conclusion

It is seen that widespread use of energy efficient windows can contribute for efficient utilization of energy in three ways:

(i) by reducing the capacity of installed air conditioning system for the same output service resulting in reduced load to the utility.

(ii) By lowering the electricity consumption for operating the air-conditioning system.

(iii) By reducing the electricity consumption due to lighting by the optimal use of natural daylight in buildings which are used during daytime.

The above mentioned energy management techniques are often more cost effective in providing a given level of energy services than any energy supply strategy. In addition, these windows provide a better comfort condition inside the building improving the productivity and health of the occupants. These windows act as excellent sound barriers and shield the interior from UV radiation.

Both the future and the existing stock of air-conditioned buildings in India represent a potential area of energy conservation activity. The energy efficiency results in concomitant reduction of net

U is the co-efficient of thermal transmittance of the glazing (W/m^2K) and T_o and T_i are respectively the outside and inside temperatures of the building. The sign of the above equation depends on the time of the day and the season. The performance characteristics of typical glazings are given below:

Table I: Performance Characteristics of a Few Typical Glazings

Glazing Type	SC	T_v	k_e	U (W/m^2K)
Single glazing	1.00	0.91	0.91	6.46
Double glazing	0.82	0.78	0.95	3.31
Heat reflecting with plastic	0.56	0.74	1.32	2.50
Tinted glass (Green)	0.72	0.75	1.04	6.45
Tinted glass(Green)+ clear glass	0.58	0.66	1.14	3.37
Low-e coating with glass	0.67	0.74	1.10	1.94
Low-e double glazing	0.85	0.78	0.92	2.27

The above equation (no.5), when read in conjunction with the values depicted in Table 1, clearly shows that in a warm climate the heat gain Q can substantially be reduced when appropriate glazings with desirable properties are used. It is essentially by adjusting SC and U and keeping in view the requirement of daylight. Similarly in a cold climate, it is possible to maximize Q by manipulating the solar spectrum and minimizing heat losses to the outside. This would make it possible to design a HVAC (Heating, ventilation & air-conditioning) system with considerable reduced loads. Because of their selective properties, these glazings will allow daylight to come inside the building and the view through the windows will not be hindered.

It is now possible to carry out simulation on energy demand of a building at a particular climate and to find out the glazing types that must be used for optimum output. A design exercise undertaken will clearly indicate the glazing types in different orientations, the lighting system, roof/wall insulation and the HVAC capacity to be installed. It is, however, always desirable to incorporate climate responsive building design principles at the initial stage of building design.

Environmental impact

Chlorofluorocarbons (CFCs) are widely being used for refrigeration and air-conditioning applications since 1930s. The chlorine atoms of these halogenated hydrocarbons react with the ozone present in stratosphere and result in depletion of ozone layer. Ozone holes allow the harmful ultra-violet rays to reach the surface of the earth. The Montreal Protocol (1987) on phasing out of ozone depleting substances (ODSs) including CFCs and its subsequent amendments (London, 1990 and Copenhagen, 1992) has lead to the ban on manufacture of CFCs in most of the countries of Europe, USA and Japan. According to the protocol, the developing countries have to meet these requirements by 2010 AD. CFCs are also green house gases (GHGs) and contribute to global warming. The Global Warming Potential (GWP) for the CFCs is high (Aneja & Sethi, 1999).

HCFC-22 has currently been accepted as a transition solution. HCFCs are, therefore, known as 'bridge refrigerants' since their phase-out dates are extended upto 2040 AD. HCFCs also contain chlorine but in much smaller amount than CFCs. As a result, these new refrigerants have very little ozone depletion potential. But HCFCs do contribute to the green house effect.

environmental emission. Thus energy efficient windows can be offered as a DSM (Demand Side Management) option to the electric utilities.

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Note: The views expressed in this paper are those of the author in his individual capacity and do not necessarily reflect the views of the organization he belongs to.

Energy efficiency in architecture: an overview of design concepts and architectural interventions

Buildings, as they are designed and used today, contribute to serious environmental problems because of excessive consumption of energy and other natural resources. The close connection between energy use in buildings and environmental damage arises because energy-intensive solutions sought to construct a building and meet its demands for heating, cooling, ventilation, and lighting cause severe depletion of invaluable environmental resources.

However, buildings can be designed to meet the occupant's need for thermal and visual comfort at reduced levels of energy and resources consumption. Energy resource efficiency in new constructions can be effected by adopting an integrated approach to building design. The primary steps in this approach are listed below.

- *Incorporate solar passive techniques in a building design to minimize load on conventional systems (heating, cooling, ventilation, and lighting)* Passive systems provide thermal and visual comfort by using natural energy sources and sinks, e.g. solar radiation, outside air, sky, wet surfaces, vegetation, and internal gains. Energy flows in these systems are by natural means such as radiation, conduction, and convection with minimal or no use of mechanical means. The solar passive systems vary from one climate to the other. For example, in a cold climate, an architect's aim would be to design a building in such a way that solar gains are maximized, but in a hot climate, the architect's primary aim would be to reduce solar gains, and maximize natural ventilation.
- *Design energy-efficient lighting and HVAC (heating, ventilation, and air-conditioning) systems* Once the passive solar architectural concepts are applied to a design, the load on conventional systems (HVAC and lighting) is reduced. Further, energy conservation is possible by judicious design of the artificial lighting and HVAC system using energy-efficient equipment, controls, and operation strategies.
- *Use renewable energy systems (solar photovoltaic systems / solar water heating systems) to meet a part of building load* The pressure on the earth's non-renewable resources can be alleviated by judicious use of earth's renewable resources, i.e. solar energy. Use of solar energy for meeting electrical needs of a building can further reduce consumption of conventional forms of energy.
- *Use low energy materials and methods of construction and reduce transportation energy* An architect should also aim at efficient structural design, reduced use of transportation energy and high energy building material (glass, steel, etc.) and use of low energy building materials.

Thus, in brief, an energy-efficient building balances all aspects of energy use in a building – lighting, space-conditioning, and ventilation – by providing an optimized mix of passive solar design strategies, energy-efficient equipment, and renewable sources of energy. Use of materials with low embodied energy also forms a major component in energy-efficient building designs.

Architects can achieve energy efficiency in the buildings they design by studying the macro and microclimate of the site, applying bioclimatic architectural principles to combat the adverse conditions, and taking advantage of the desirable conditions. A few common design elements that directly or indirectly affect thermal comfort conditions and thereby the energy consumption in a building are listed below.

- Landscaping
- Ratio of built form to open spaces
- Location of water bodies
- Orientation
- Planform
- Building envelope and fenestration.

However, in extreme climatic conditions, one cannot achieve comfortable indoor conditions by these design considerations alone. There are certain tested and established concepts, which, if applied to a design in such climatic conditions, are able to largely satisfy the thermal comfort criterion. These are classified as advanced passive solar techniques. The two broad categories of advanced concepts are (1) passive heating concepts (direct gain system, indirect gain system, sunspaces, etc.) and (2) passive cooling concepts (evaporative cooling, ventilation, wind tower, earth-air tunnel, etc.).

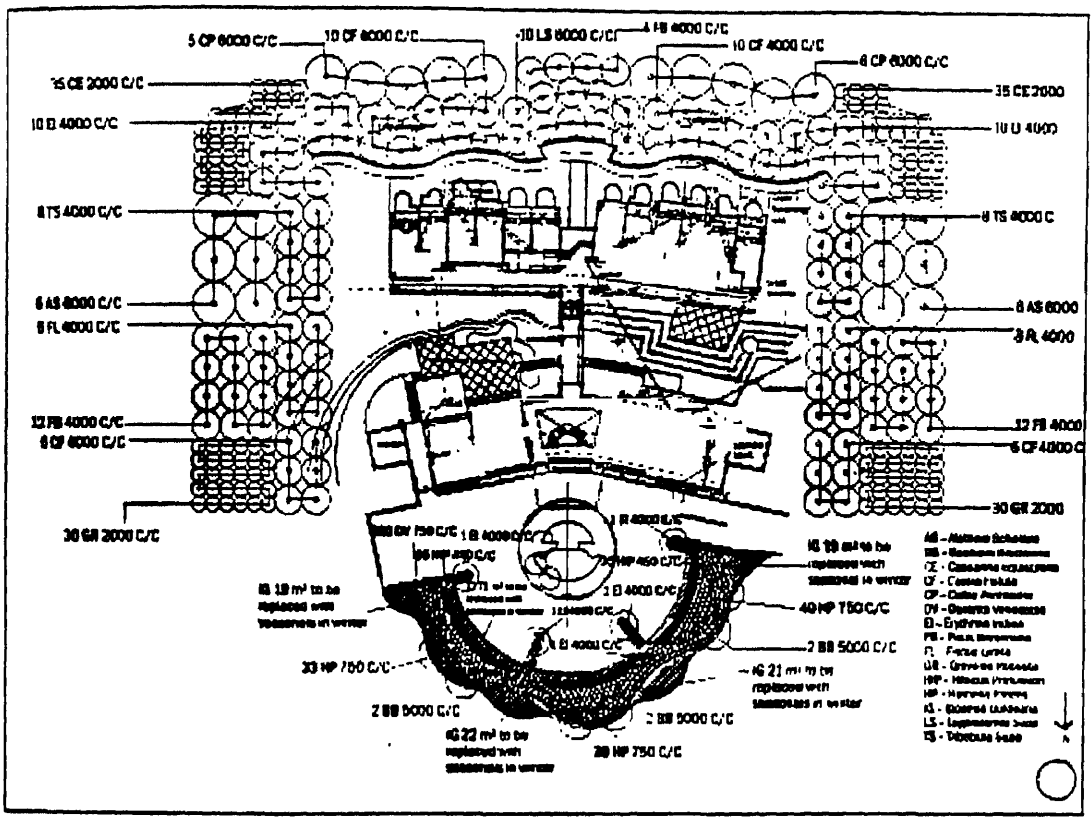
The commonly considered design elements for achieving lower energy consumption in a building are discussed below.

Common design elements

Landscaping

Landscaping is an important element in altering the microclimate of a place. Proper landscaping reduces direct sun from striking and heating up building surfaces. It prevents reflected light carrying heat into a building from the ground or other surfaces. Landscaping creates different airflow patterns and can be used to direct or divert the wind advantageously by causing a pressure difference. Additionally, the shade created by trees and the effect of grass and shrubs reduce air temperatures adjoining the building and provide evaporative cooling. Properly designed roof gardens help to reduce heat loads in a building. A study shows that the ambient air under a tree adjacent to the wall is about 2 °C to 2.5 °C lower than that for unshaded areas (Bansal, Hauser, and Minke 1994).

Trees are the primary elements of an energy-conserving landscape. Climatic requirements govern the type of trees to be planted. Planting deciduous trees on the southern side of a building is beneficial in a composite climate Deciduous plants such as mulberry or Champa cut off direct sun during summer, and as these trees shed leaves in winter, they allow the sun to heat the buildings in winter This landscaping strategy has been adopted to shade the southern side of the RETREAT (Resource Efficient TERI Retreat for Environmental Awareness and Training) building of TERI



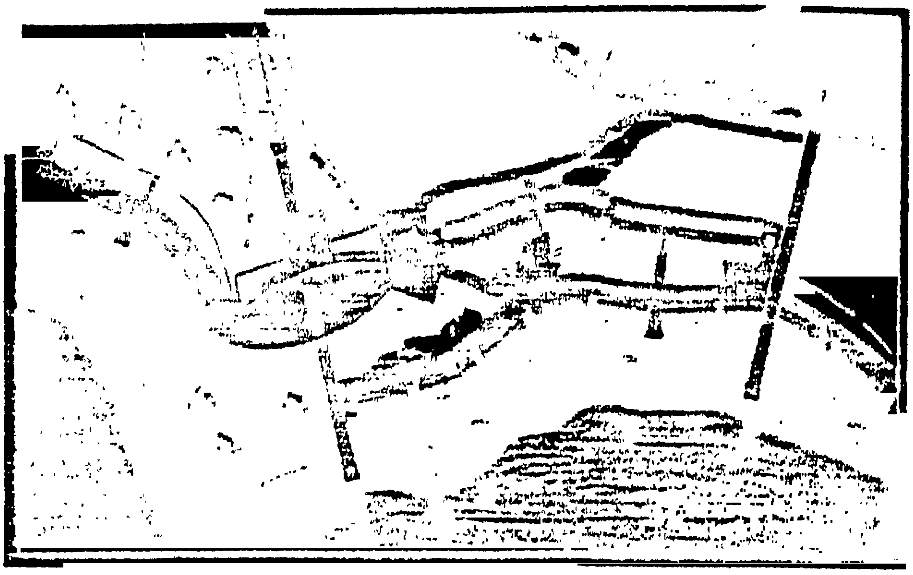
▲ The RETREAT building has deciduous trees on the south side to cut off summer gains. These trees shed leaves during winter so that winter solar gains are not cut off. Wind breaks are provided in the north and north-east to protect from the winter winds

Building form/surface-to-volume ratio

The volume of space inside a building that needs to be heated or cooled and its relationship with the area of the envelope enclosing the volume affect the thermal performance of the building. This parameter, known as the S/V (surface-to-volume) ratio, is determined by the building form. For any given building volume, the more compact the shape, the less wasteful it is in gaining/losing heat. Hence, in hot and dry regions and cold climates, buildings are compact in form with a low S/V ratio to reduce heat gain and losses, respectively. Also, the building form determines the airflow pattern around the building, directly affecting its ventilation. The depth of a building also determines the requirements for artificial lighting—greater the depth, higher the need for artificial lighting.

Location of water bodies

Water is a good modifier of microclimate. It takes up a large amount of heat in evaporation and causes significant cooling especially in a hot and dry climate. In humid climates, water should be avoided as it adds to humidity. Water has been used effectively as a modifier of microclimate in the WALMI (Water and Land Management Institute) building complex in Bhopal.



▲ A view of the WALMI building. The flowing form overlooks a water body which has been used to advantage for modification of the microclimate

Orientation

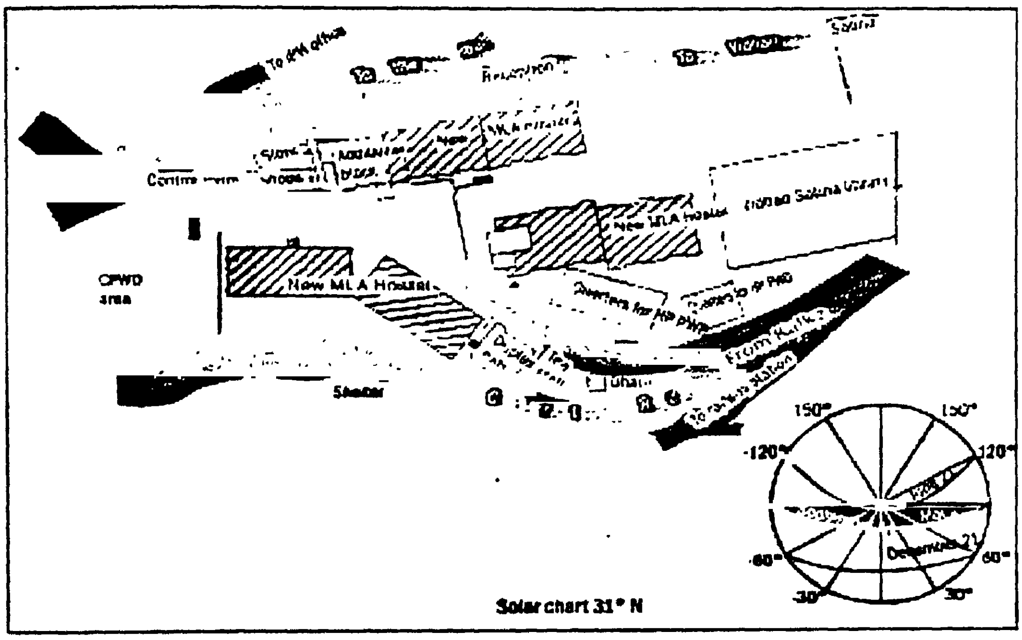
Building orientation is a significant design consideration, mainly with regard to solar radiation and wind. In predominantly cold regions, buildings should be oriented to maximize solar gain; the reverse is advisable for hot regions. In regions where seasonal changes are very pronounced, both the situations may arise periodically. For a cold climate, an orientation slightly east of south is favoured (especially 15 degrees east of south), as this exposes the unit to more morning than afternoon sun and enables the house to begin to heat during the day.

This has been amply demonstrated in the MLA Hostel building at Shimla. Similarly, wind can be desirable or undesirable. Quite often, a compromise is required between sun and wind orientations. With careful design, shading and deflecting devices can be incorporated to exclude the sun or redirect it into the building, just as wind can be diverted or directed to the extent desired.

Building envelope and fenestration

The building envelope and its components are key determinants of the amount of heat gain and loss and wind that enters inside The primary elements affecting the performance of a building envelope are

- materials and construction techniques
- roof
- walls
- fenestration and shading
- finishes.



▲ The building blocks in the MLA hostel, Shimla, located in the cold and cloudy zone, are oriented due south (±15 degrees) for direct solar gain. They are spaced apart so as to eliminate shadows of one building over the other, even for the longer winter shadows. It was proposed that all bedrooms be south-facing to avail of the benefit of south exposure

Materials and construction techniques

Material with low embodied energy

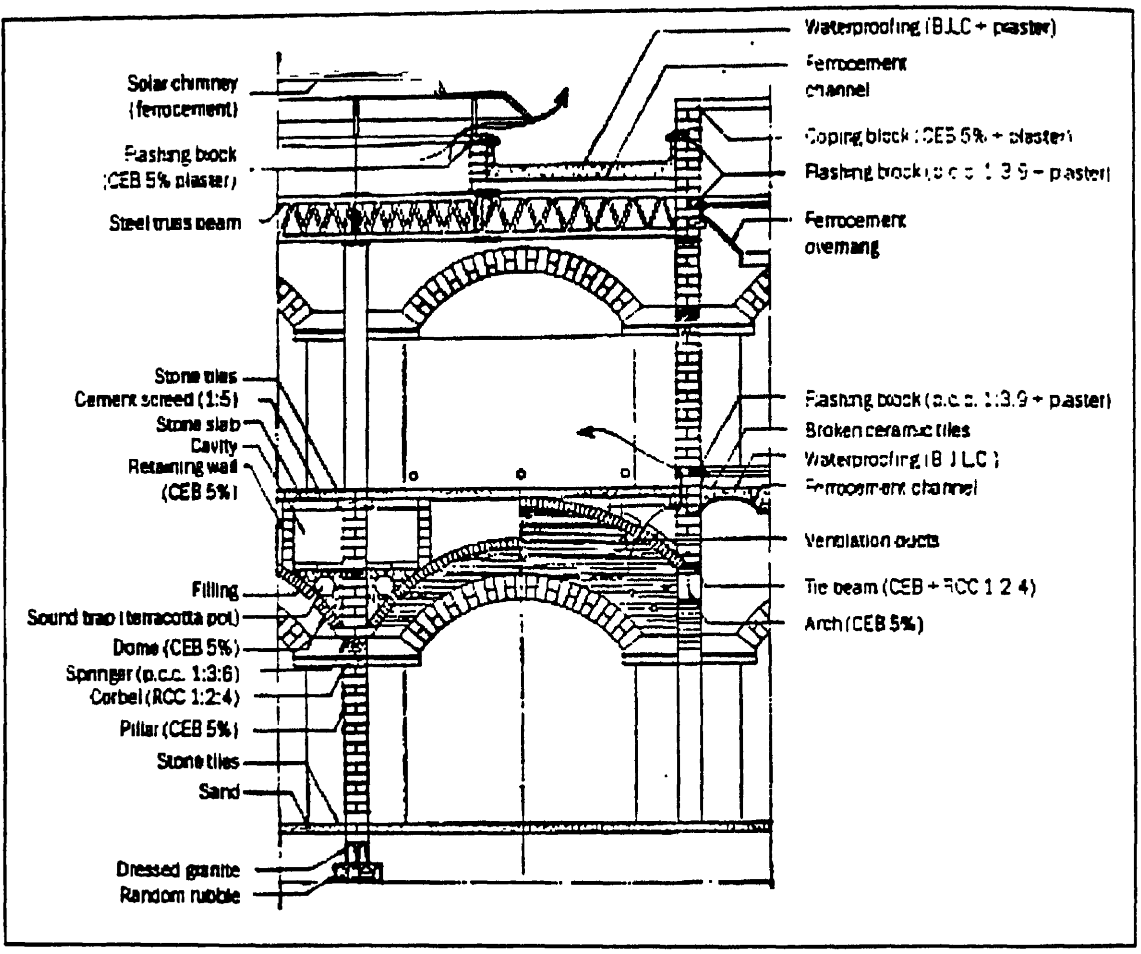
Choice of building materials is important in reducing the energy content of buildings. Strain on conventional energy can be reduced by use of low-energy materials, efficient structural design, and reduction in transportation energy.

The choice of materials also helps to maximize indoor comfort. Use of materials and components with low embodied energy has been demonstrated in various buildings in Auroville. The Visitors' Centre at Auroville uses innovative materials and construction techniques to reduce embodied energy of the building and attain the desired comfort conditions conducive to the warm and humid climate.

Thermal insulation

Insulation is of great value when a building requires mechanical heating or cooling insulation helps reduce the space-conditioning loads. Location of insulation and its optimum thickness are important. In hot climates, insulation is placed on the outer face (facing exterior) of the wall so that thermal mass of the wall is weakly coupled with the external source and strongly coupled with the interior (Bansal, Hauser, and Minke 1994).

Use of 40-mm thick expanded polystyrene insulation on walls and vermiculite concrete insulation on the roof has brought down space-conditioning loads of the RETREAT building by about 15%.



▲ Sectional details showing use of alternative construction techniques Ferrocement solar chimney and ventilation duct in corbelled arch demonstrates use of passive solar ventilation techniques

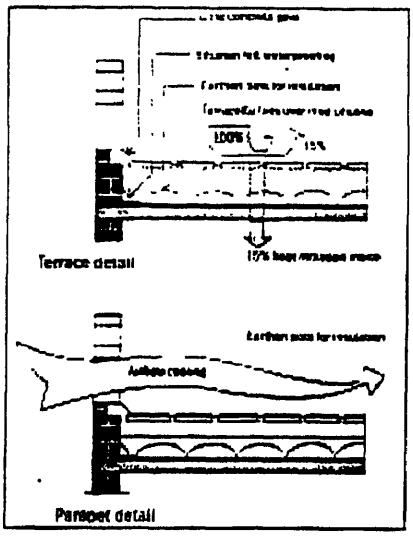
Table 1 Energy contents of commonly used building materials

Building	*Elements/materials*	*KWh/m^3* (in situ)
Cement concrete	1:5:10	402
Lime concrete with brick ballast	1:4:8	1522 (80% in brick)
Brick masonry	1:5	676
Brick masonry	1:4	709
Random rubble masonry	1:4	267
Stabilized mud with 6% lime	–	197
Stabilized mud with 10% lime	–	320
RCC roof (10 cm)	–	174/m^2
Stone slabs in RCC joists	–	132/m^2
Cement plaster	1:4	20.65/m^2
Cement plaster	1:6	15.09/m^2
Lime surkhi	1:4	11.05/m^2

Source Gupta (1994)

Roof

The roof receives significant solar radiation and plays an important role in heat gain/losses, daylighting, and ventilation. Depending on the climatic needs, proper roof treatment is essential. In a hot region, the roof should have enough insulating properties to minimize heat gains. A few roof protection methods are as follows.



▲ Roof details showing use of earthern pots for roof insulation

◀ Broken China mosaic can be used as topmost layer in roof for reflection of incident radiation

- A cover of deciduous plants or creepers can be provided. Evaporation from leaf surfaces will keep the rooms cool.
- The entire roof surface can be covered with inverted earthen pots. It is also an insulating cover of still air over the roof.
- A removable cover is an effective roof-shading device. This can be mounted close to the roof in the day and can be rolled up to permit radiative cooling at night. The upper surface of the canvas should be painted white to minimize the radiation absorbed by the canvas and consequent conductive heat gain through it.
- Effective roof insulation can be provided by using vermiculite concrete. This has been used in the RETREAT building at Gual Pahari (near New Delhi) and has reduced roof conduction by 60%.

▲ The skylight on the roof of the West Bengal Renewable Energy Development Agency office building provides natural light for inner office spaces and is connected to the office spaces for inducing ventilation by stack effect

The roof can also be used advantageously for effective ventilation and daylighting by incorporating vents and skylights. This has been demonstrated effectively in the recently constructed office building of the WBREDA (West Bengal Renewable Energy Development Agency) in Kolkata.

Walls

Walls are a major part of the building envelope and receive large amounts of solar radiation. The heat storage capacity and heat conduction property of walls are key to meeting desired thermal comfort conditions. The wall thickness, material, and finishes can be chosen based on the heating and cooling needs of the building. Appropriate thermal insulation and air cavities in walls reduce heat transmission into the building, which is the primary aim in a hot region.

Air cavities

Air cavities within walls or an attic space in the roof ceiling combination reduce the solar heat gain factor, thereby reducing space-conditioning loads. The performance improves if the void is ventilated. Heat is transmitted through the air cavity by convection and radiation. A cavity represents a resistance, which is not proportional to its thickness. For a thickness >20 mm, the resistance to heat flow remains nearly constant. Ventilated air does not reduce radiative heat transfer from roof to ceiling. The radiative component of heat transfer may be reduced by using low emissivity or high reflective coating (e.g. aluminium foil) on either surface facing the cavity. With aluminium foil attached to the top of ceiling, the resistance for downward heat flow increases to about 0.7 m^2k/W, compared to 0.21 m^2k/W in the absence of the foil (Bansal, Hauser, and Minke 1994).

Fenestration and shading

Of all the elements in the building envelope, windows and other glazed areas are most vulnerable to heat gain or losses. Proper location, sizing, and detailing of windows and shading form an important part of bioclimatic design as they help to keep the sun and wind out of a building or allow them when needed.

The location of openings for ventilation is determined by prevalent wind direction. Openings at higher levels naturally aid in venting out hot air. Size, shape, and orientation of openings moderate air velocity and flow in the room; a small inlet and a large outlet increase the velocity and distribution of airflow through the room. When possible, the house should be so positioned on the site that it takes advantage of prevailing winds. The prevailing wind direction is from the south/south-east during summer. The recommendations in IS:3362-1977 code of practices for natural ventilation of residential buildings (first revision) should be satisfied in the design of windows for lighting and ventilation. There should be sufficient air motion in hot-humid and warm-humid climates In such areas, fans are essential to provide comfortable air motion indoors. Fenestrations having 15%-20% of floor area are found adequate for both ventilation and daylighting in hot and dry, and hot and humid regions.

Natural light is also admitted into a building through glazed openings Thus, fenestration design is primarily governed by requirements of heat gain and loss, ventilation, and daylighting. The important components of a window that govern these are the glazing systems and shading devices

Glazing systems

Before recent innovations in glass, films, and coatings, a typical residential window with one or two layers of glazing allowed roughly 75%–85% of the solar energy to enter a building. Internal shading devices such as curtains or blinds could reflect back some of that energy outside the building. The weak thermal characteristics of windows became a prime target for research and development in an attempt to control the indoor temperature of buildings. A detailed write-up on energy-efficient glazing system is provided in Appendix V.

Windows admit direct solar radiation and hence promote heat gain. This is desirable in cold climates, but is critical in hot climates. The window size should be kept minimum in hot and dry regions. For example, in Ahmedabad, if glazing is taken as 10% instead of 20% of the floor area, then the number of uncomfortable hours in a year can be reduced by as much as 35% (Nayak, Hazra, and Prajapati 1999).

Shading devices

Heat gain through windows is determined by the overall heat loss coefficient U-value (W/m^{2}K) and the solar energy gain factor, and is much higher as compared to that through solid wall. Shading devices for windows and walls thus moderate heat gains into the building. In a low-rise residential building in Ahmedabad (hot and dry climate), shading a window by a horizontal 0.76-m deep *chhajja* can reduce the maximum room temperature by 4.6 °C (from 47.7 to 43.1 °C). Moreover, the number of uncomfortable hours in a year with temperatures exceeding 30 °C can be reduced by 14% ((Nayak, Hazra, and Prajapati 1999).

Shading devices are of various types (Bansal, Hauser, and Minke 1994).

1 Moveable opaque (roller blind, curtains, etc.) can be highly effective in reducing solar gains but eliminate view and impede air movement.
2 Louvres (adjustable or fixed) affect the view and air movement to some degree.
3 Fixed overhangs.

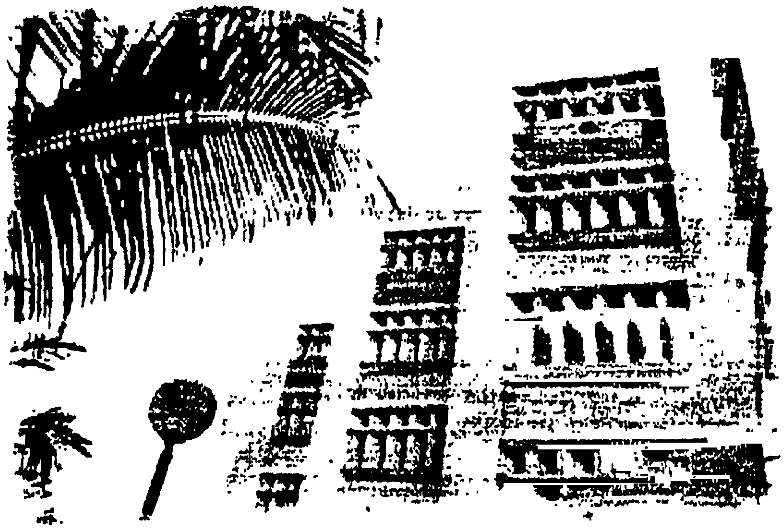
Relative advantages and disadvantages of these shading devices are given below.

Moveable blinds or curtains

- Block the transmission of solar radiation through glazed windows, especially on the east and west walls
- In hot and dry climates, when ambient air is hotter than room air, they help to reduce convective heat gain
- In warm, humid climates, where the airflow is desirable, they impede ventilation
- For air-conditioned buildings, where the flow of outside air is to be blocked, they can reduce cooling load.

Overhangs and louvres

- Block that part of the sky through which sunlight passes
- Overhangs on south-oriented windows provide effective shading from the high-altitude sun
- An extended roof shades the entire north or south wall from the noon sun



The office building for the West Bengal Pollution Control Board is a landmark of energy and resource conscious architecture in this region. Efficient planning and carefully designed shading devices, fenestration design and efficient lighting design has brought about 40% energy savings over a conventional building of similar size and function This picture shows the east facade with inclined louvres to cut off solar gains

- East and west openings need much bigger overhangs, which may not be possible and can be achieved by porticos or verandahs on these sides or by specially designed louvres to suit the building requirements.

The scientific design of fenestration and shading devices in the West Bengal Pollution Control Board building has brought down the projected energy consumption substantially (TERI 1996).

Finishes

The external finish of a surface determines the amount of heat absorbed or rejected by it. For example, a smooth and light colour surface reflects more light and heat in comparison to a dark colour surface. Lighter colour surfaces have higher emissivity and should be ideally used for warm climate.

Advanced passive heating techniques

Advanced passive heating techniques are used by architects in building design to achieve thermal comfort conditions in cold climate Passive solar heating systems can be broadly classified into direct gain systems and indirect gain systems

Direct gain

Direct gain is the most common passive solar system. In this system, sunlight enters rooms through windows, warming the interior space. The glazing system is generally located on the southern side to receive maximum sunlight during winter (in the northern hemisphere). The glazing system is usually double-glazed, with insulating curtains to reduce heat loss during night. South-facing glass admits solar energy into the building, where it strikes thermal storage materials such as floors or walls made of adobe, brick, concrete, stone, or water. The direct gain system uses 60%–75% of solar energy striking the windows. The interior thermal mass tempers the intensity of heat during the day by absorbing heat. At night, the thermal mass radiates heat into the living space, thus warming the spaces.

Direct gain can be achieved by various forms of openings such as clerestories and skylight windows designed for the required heating. Direct gain systems have been used for day-use rooms by architect Sanjay Prakash in the residence for Mohini Mullick at Bhowali. The user is extremely satisfied with the thermal performance of the direct gain system in this residence.

he direct gain system of the Bhowali house. The picture ghlights the fully glazed walls for e day-use rooms from inside

Direct gain systems have some limitations. They cause large temperature savings (typically 10 °C) because of large variations in input of solar energy. In direct gain systems, the interior of the house receives direct sunlight, which results in the degradation of the interior furnishings, etc. However, being relatively simple to construct and inexpensive, they are by far the most common systems used worldwide.

Indirect gain system

In an indirect gain system, thermal mass is located between the sun and the living space. The thermal mass absorbs the sunlight that strikes it and transfers it to the living space. The indirect gain system uses 30%–45% of the sun's energy striking the glass adjoining the thermal mass. A few commonly used indirect gain systems are discussed below.

Trombe wall

A Trombe wall is a thermally massive wall with vents provided at the top and bottom. It may be made of concrete, masonry, adobe, and is usually located on the southern side (in the northern hemisphere) of a building in order to maximize solar gains. The outer surface of the wall is usually painted black for maximizing absorption and the wall is directly placed behind glazing with an air gap in between.

Solar radiation is absorbed by the wall during the day and stored as sensible heat. The air in the space between the glazing and the wall gets heated up and enters the living spaces by convection through the vents. Cool air from the rooms replaces this air, thus setting up a convection current. The vents are closed during night, and heat stored in the wall during the day heats up the living space by conduction and radiation.

Trombe walls have been extensively used in the cold regions of Leh. Various forms of Trombe walls have been tried and tested in the LEDeG Hostel at Leh.

It is worth noting that in buildings with thermal storage walls, indoor temperature can be maintained at about 15 °C when the outside temperature is as low as −11 °C (Mazria 1979).

Generally, thickness of the storage wall is between 200 mm and 450 mm, the air gap between the wall and glazing is 50–150 mm, and the total area of each row of vent is about one per cent of the storage wall area (Levy, Evans, and Gardstein 1983). The Trombe wall should be adequately shaded for reducing summer gains.

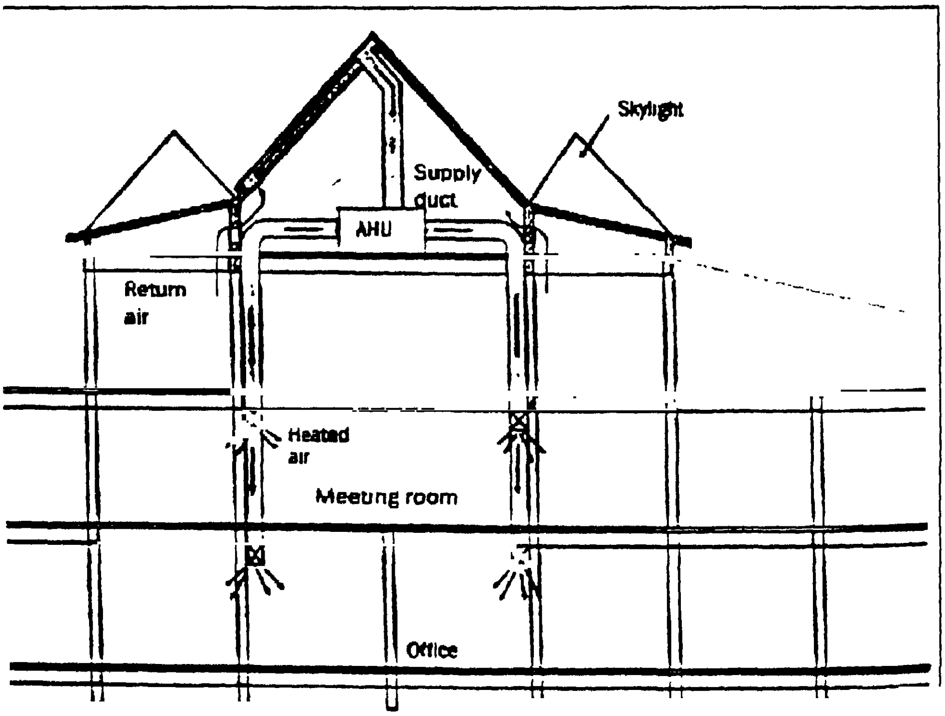
Water wall

Water walls are based on the same principle as that for Trombe walls, except that they employ water as the thermal storage material. A water wall is a thermal storage wall made up of drums of water stacked up behind glazing. It is usually painted black to increase heat absorption. It is more effective in reducing temperature swings, but the time lag is less.

Heat transfer through water walls is much faster than that for Trombe walls. Therefore, the distribution of heat needs to be controlled if it is not immediately required for heating the building. Buildings that work during daytime, such as schools and offices, benefit from the rapid heat transfer in the water wall. Overheating during summer may be prevented by using suitable shading devices.

Roof-based air heating system

In this technique, incident solar radiation is trapped by the roof and is used for heating interior spaces. In the northern hemisphere, the system usually consists of an inclined south-facing glazing and a north-sloping insulated surface on the roof. Between the roof and the insulation, an air pocket is formed, which is heated by solar radiation. A moveable insulation can be used to reduce heat loss through glazed panes during nights. There could be variations in detailing of roof air heating systems. In the Himachal Pradesh State Cooperative Bank building, south-glazing is in the form of solar collectors warming the air and a blower fan circulating the air to the interior spaces.



Part section

Sunspaces

A sunspace or solarium is the combination of direct and indirect gain systems. Solar radiation heats up the sunspace directly, which, in turn, heats up the living space (separated from the sunspace by a mass wall) by convection and conduction through the mass wall. In the northern hemisphere, the basic requirements of buildings heated by sunspace are (1) a glazed south-facing collector space attached yet separated from the building and (2) living space separated from the sunspace by a thermal storage wall. Sunspaces may be used as winter gardens adjacent to the living space. The Himurja building in Shimla has a well-designed solarium on the south wall to maximize solar gain.

Advanced passive cooling techniques

Before the turn of the century, buildings were designed to take advantage of daily temperature variations, convective breeze, shading, evaporative cooling, and radiation cooling. However, with a thoughtless imitation of the west, these concepts took a back seat and buildings became energy guzzlers. Today, with high energy costs and growing environmental concerns, many of these simpler techniques are once again becoming attractive. Passive cooling systems rely on natural heat-sinks to remove heat from the building. They derive cooling directly from evaporation, convection, and radiation without using any intermediate electrical devices. All passive cooling strategies rely on daily changes in temperature and relative humidity. The applicability of each system depends on the climatic conditions.

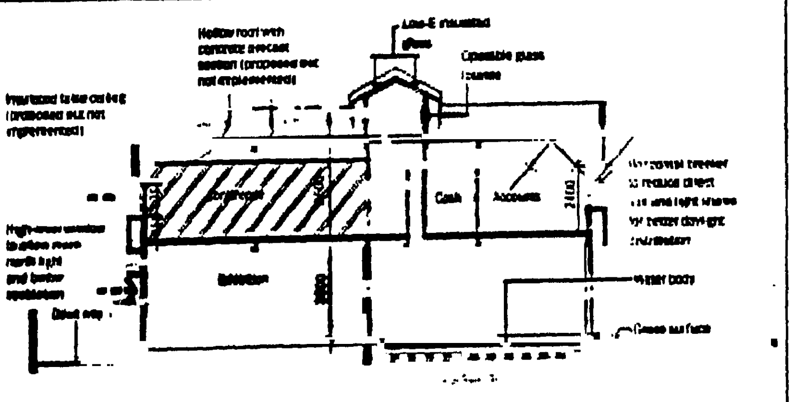
The relatively simple techniques that can be adopted to provide natural cooling in the building have been elaborated earlier.

These design strategies reduce heat gains to internal spaces. This section briefly elaborates the passive techniques that aid heat loss from the building by convection, radiation, and evaporation, or by using storage capacity of surrounding spaces, e.g. earth berming.

Ventilation

Outdoor breezes create air movement through the house interior by the 'push-pull' effect of positive air pressure on the windward side and negative pressure (suction) on the leeward side. Good natural ventilation requires

Section of the WBREDA office building showing ventilation strategies ▶


Hollow roof with concrete precast section (proposed but not implemented)
Low-E insulated glass
Openable glass louvres
Insulated false ceiling (proposed but not implemented)
Horizontal breaker to reduce direct sun and light shelf for better daylight distribution
Cash
Accounts
Exhibition
High-level window to allow more north light and better ventilation
Water body
Grass surface
Air-conditioned area
North light
South breeze

Proposed administrative-cum-office building for West Bengal Renewable Energy Development Agency. However, in the final design, two more floors were added above the first floor locating openings in opposite pressure zones. Also, designers often choose to enhance natural ventilation using tall spaces called stacks in buildings. With openings near the top of stacks, warm air can escape whereas cooler air enters the building from openings near the ground. Ventilation by creating stacks has been effectively used in the office building of the West Bengal Renewable Energy Development Agency in Kolkata. Located in a warm humid climate, induced ventilation was a primary design strategy for this building.

Innovative ventilation strategies by use of building-integrated solar chimneys have been used in Sudha and Atam Kumar's residence in the composite climate of New Delhi.

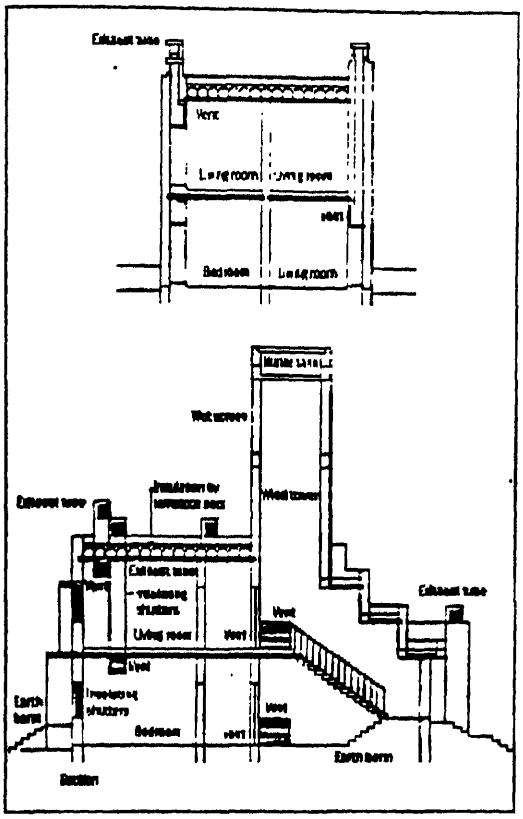
The windows, as discussed earlier, play a dominant role in inducing indoor ventilation due to wind forces. Other passive cooling techniques that induce indoor natural ventilation and are used by architects to achieve passive cooling are discussed below.

Building-integrated solar chimney in Sudha and Atam Kumar's residence in New Delhi for effective ventilation especially during humid season. The inset shows a closer view of the chimney top

Wind tower

In a wind tower, the hot air enters the tower through the openings in the tower, gets cooled, and thus becomes heavier and sinks down. The inlet and outlet of rooms induce cool air movement. In the presence of wind, air is cooled more effectively and flows faster down the tower and into the living area. After a whole day of air exchanges, the tower becomes warm in the evenings. During the night, cooler ambient air comes in contact with the bottom of the tower through the rooms. The tower walls absorb heat during daytime and release it at night, warming the cool night air in the tower. Warm air moves up, creating an upward draft, and draws cool night air through the doors and windows into the building. The system works effectively in hot and dry climates where diurnal variations are high. The Jodhpur Hostel, designed by Dr Vinod Gupta, uses wind tower for summer cooling.

A wind tower works well for individual units not for multi-storeyed apartments. In dense urban areas, the wind tower has to be long enough to be able to catch enough air. Also protection from driving rain is difficult



Courtyard effects

Due to incident solar radiation in a courtyard, the air gets warmer and rises. Cool air from the ground level flows through the louvred openings of rooms surrounding a courtyard, thus producing air flow.

At night, the warm roof surfaces get cooled by convection and radiation. If this heat exchange reduces roof surface temperature to wet bulb temperature of air, condensation of atmospheric moisture occurs on the roof and the gain due to condensation limits further cooling.

If the roof surfaces are sloped towards the internal courtyard, the cooled air sinks into the court and enters the living space through low-level openings, gets warmed up, and leaves the room through higher-level openings. However, care should be taken that the courtyard does not receive intense solar radiation, which would lead to conduction and radiation heat gains into the building. Intensive solar radiation in the courtyard also produces immense glare.

Earth air tunnels

Daily and annual temperature fluctuations decrease with the increase in depth below the ground surface. At a depth of about 4 m below ground, the temperature inside the earth remains nearly constant round the year and is nearly equal to the annual average temperature of the place. A tunnel in the form of a pipe or otherwise embedded at a depth of about 4 m below the ground will acquire the same temperature as the surrounding earth at its surface and, therefore, the ambient air ventilated though this tunnel will get cooled in summer and warmed in winter and this air can be used for cooling in summer and heating in winter.

Earth air tunnel has been used in the composite climate of Gurgaon in the RETREAT building. The living quarters (the south block of RETREAT) are maintained at comfortable temperatures (approximately between 20 °C and 30 °C) round the year by the earth air tunnel system, supplemented, whenever required, with a system of absorption chillers powered by liquefied natural gas during monsoons and with an air washer during dry summer. However, the cooler air underground needs to be circulated in the living space. Each room in the south block has a solar chimney; warm air rises an escapes through the chimney, which creates an air current for the cooler air from the underground tunnels to replace the warm air. Two blowers installed in the tunnels speed up the process. The same mechanism supplies warm air from the tunnel during winter.

Evaporative cooling

Evaporative cooling lowers indoor air temperature by evaporating water. It is effective in hot and dry climate where the atmospheric humidity is low. In evaporative cooling, the sensible heat of air is used to evaporate water, thereby cooling the air, which, in turn, cools the living space of the building. Increase in contact between water and air increases the rate of evaporation.

The presence of a water body such as a pond, lake, and sea near the building or a fountain in a courtyard can provide a cooling effect. The most commonly used system is a desert cooler, which comprises water, evaporative pads, a fan, and pump. Evaporative cooling has been tried as a roof-top installation at the Solar Energy Centre, Gurgaon. However, the system has now become defunct due to poor water supply in the area.

Passive downdraught cooling

Evaporative cooling has been used for many centuries in parts of the Middle East, notably Iran and Turkey. In this system, wind catchers guide outside a over water-filled pots, inducing evaporation and causing a significant drop i temperature before the air enters the interior. Such wind catchers become primary elements of the architectural form also. Passive downdraught evaporative cooling is particularly effective in hot and dry climates. It has been used to effectively cool the Torrent Research Centre in Ahmedabad.

▲ Passive downdraught cooling has been successfully used at the Torrent Research Centre, Ahmedabad [illegible]

Daylighting

Daylighting has a major effect on the appearance of space and can have considerable energy-efficiency implications, if used properly Its variability and subtlety is pleasing to the occupants in contrast to the relatively monotonous environment produced by artificial light. It helps to create optimum working conditions by bringing out the natural contrast and colour of objects. The presence of natural light can bring a sense of well being and awareness of the wider environment. Daylighting is important particularly in commercial and other non-domestic buildings that function during the day. Integration of daylighting with artificial lighting brings about considerable savings in energy consumption.

A good daylighting system has a number of elements, most of which must be incorporated into the building design at an early stage. This can be achieved by considering the following in relation to the incidence of daylight on the building.

- Orientation, space organization, and geometry of the space to be lit
- Location, form, and dimensions of the fenestrations through which daylight will enter
- Location and surface properties of internal partitions that affect daylight distribution by reflection
- Location, form, and dimensions of shading devices that provide protection from excessive light and glare
- Light and thermal characteristics of the glazing materials.

Daylight integration is an important aspect of energy-efficient building design, and most of the case studies covered in this book have innovative daylighting strategies.

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[data courtesy Sanjay P, Rakesh Ahuja, and Geeta V]

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Green buildings

Mili Majumdar
Energy environment technology
TERI

Preview of presentation

- Concept of green buildings
- Simple and advanced concepts of passive architecture
- Sustainable habitat - a case study

Green building design

- Sustainable site planning
- Energy efficiency(passive design, use of renewable sources of energy, use of efficient and eco friendly equipment)
- Use of environment friendly construction materials and techniques
- Minimize generation of waste and recycle waste and Maximize water efficiency
- Maintain indoor environmental quality
- Monitoring and verification

Main climatic zones of India

Cold and sunny (Leh)
Cold and cloudy (Shimla)
Hot and dry (Ahmedabad)
Warm and humid (Kolkata)
Composite (Delhi)
Moderate (Bangalore)

How to reduce energy use in buildings by architectural interventions?-

Solar passive techniques

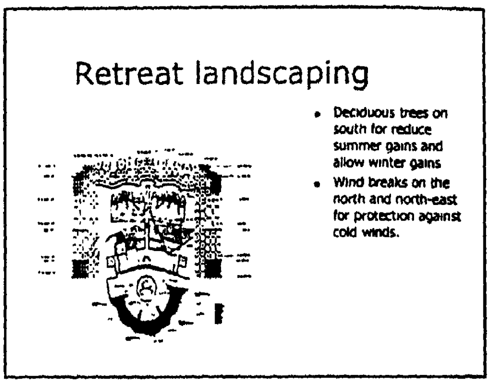
Simple techniques
Advanced techniques
examples for each

Concepts of passive architecture: simple and advanced

- Simple - common design elements which are integral part of any building
  - landscaping
  - built form/surface to volume ratio
  - Location of water bodies
  - orientation
  - Building envelope and fenestration
    - Walls
    - roof
    - fenestration and shading
    - finishes
    - Material and construction techniques

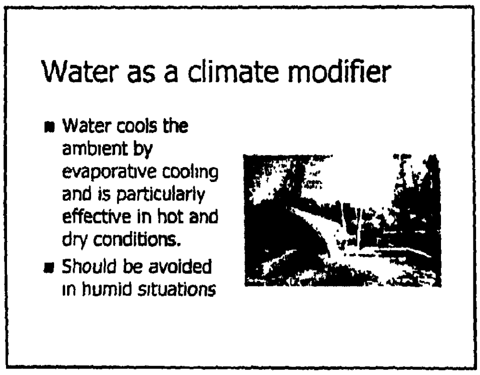
Landscaping

- Shrubs or small trees can be used to shade air conditioning unit to improve its performance. However, plants should not be closer than 1m to the compressor for good airflow and access.
- Ambient air adjacent to the wall is lower by 2-2.5 deg C lower than in unshaded areas
- The temperature above ground cover will be 5-8°C cooler than above a heat absorbent material such as asphalt.
- Water acts as a very good modifier of microclimate, especially in **hot dry climate**. In **humid climates**, they should be avoided as they add to humidity.



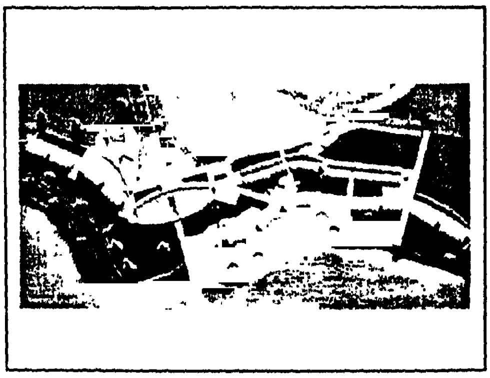
Retreat landscaping

- Deciduous trees on south for reduce summer gains and allow winter gains
- Wind breaks on the north and north-east for protection against cold winds.



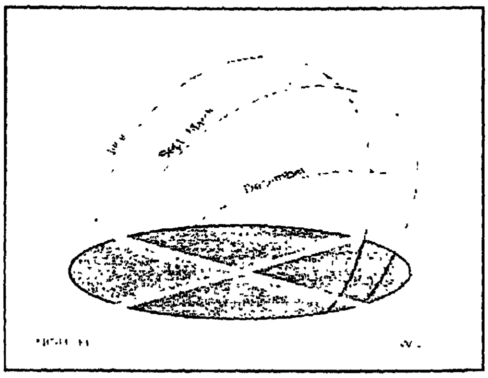
Water as a climate modifier

- Water cools the ambient by evaporative cooling and is particularly effective in hot and dry conditions.
- Should be avoided in humid situations

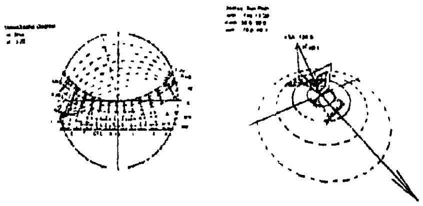


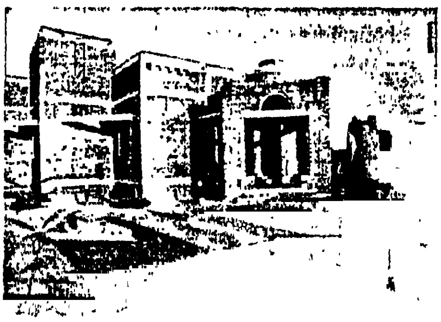
Surface to volume ratio

- The more compact the shape, the less wasteful it is in heat loss and gain.
- In hot, dry and in cold climates, the buildings are compact in form with low surface to volume ratio to reduce heat gains and losses respectively.



Solar path and Shading analysis





Building envelope: roof

- Roof receives significant solar radiation
- Roof insulation particularly important for hot climates
  - inverted earthen pots
  - insulating material e.g vermiculite insulation
  - reflective surfaces e.g broken china mosaic , reflective paints for inclined roofs

Roof- contd.

Roof can be used advantageously for effective ventilation and daylighting , especially is warm and humid climates.

Wall

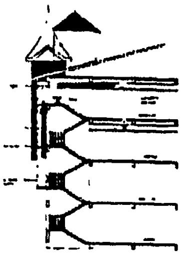
- Receives large amount of solar radiation
- For cold climate, wall treatment to maximize heat gains (direct gain systems ,Trombe walls) and
- vice versa in warmer climates (
- by application of insulation , cavities, shading
  - e.g Expanded polystyrene,
  - heat reflecting paints,
  - use of wall materials of low U values e.g.autoclaved aerated concrete blocks , 200mm wall has U value of 0.67W/sq.m deg C as compared to 1.95 W/sq.m deg C for solid brick wall

Effect of insulation in Retreat

- Expanded polystyrene insulation 40mm thick on walls, with welded wire mesh covering and 1:4 coarse sand plaster coating, 18 mm thick.
- Expanded Vermiculite concrete (density of vermiculite is 250kg/cu.m) mix , with water laid to slope.
- Location of insulation and its optimum thickness is very important e.g. in hot climate insulation is placed on the outer face (facing exterior) to wall so that the thermal mass of wall is weakly coupled with external source and strongly coupled with interior.

Insulation reduced cooling loads by 10%

Walls- for heating



Himachal pradesh
State cooperative bank

Fenestration and shading devices

- Windows are most vulnerable to heat gains and losses.
- Heat gain through glazed surfaces determined by the direct gain component (defined by shading coefficient) and U- value
- Window size and location should be determined by:
  - Orientation
  - Glazed area
  - Glazing type
  - external shading
  - wind direction

Effect of change of glazing type, orientation, and shading on heat gain through fenestration in New Delhi

Solar Gain

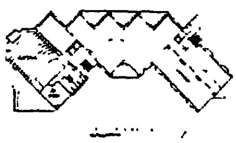
Glass	Direction	Area	SHGF	SC	Btu/hr	
Plane	North	26.4	16	1	422.4	Not shaded from outside or inside
Plane	North	26.4	16	0.56	236.5	Shaded from inside through venetian blind of light colour
Plane	North	26.4	16	0.15	63.4	Shaded from outside through venetian blind of light colour
Low-e	North	26.4	16	0.22	92.9	Not shaded from outside or inside
Plane	West	26.4	164	1	4329.6	Not shaded from outside or inside
Plane	West	26.4	164	0.56	2424.6	Shaded from inside through venetian blind of light colour
Plane	West	26.4	164	0.15	649.4	Shaded from outside through venetian blind of light colour
Low-e	West	26.4	164	0.22	952.5	Not shaded from outside or inside

Transmission gain

Glass	Direction	Area	TD	U	Btu/hr
Plane	North/west	26.4	33	1.13	984.5
Low-e	North/west	26.4	33	0.34	296.2

Window design optimization- WBPCB building

- Design optimisation yielded 40% annual energy savings over initial design

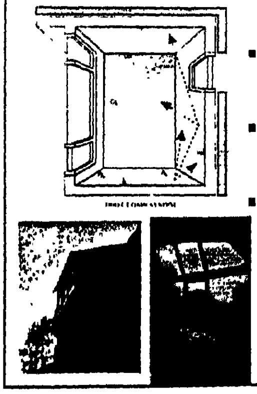


Advanced concepts
- Heating
- Cooling

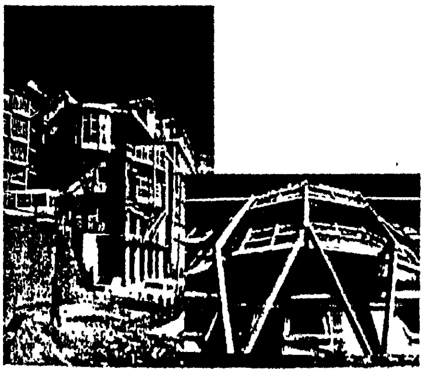
- Heating

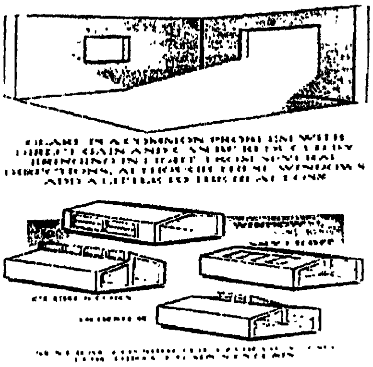
Direct gain systems
Indirect gain systems
Combined systems

Direct gain



- South glazing to attract maximum solar radiation in summer to heat the walls, floors and objects .
- High thermal mass with exterior insulation to reduce the fluctuations in room temperature .
- Maximum solar gain in winter when sun angles are low and minimum solar gain in summer when sun angles are high.





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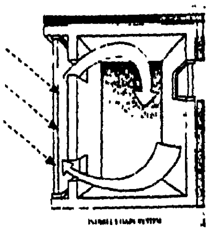
Indirect gain systems: Trombe wall

- Doubly glazed dark coloured massive south wall heated up during daytime.
- Air entering the space between glazing and wall gets heated up and enters the living space through vents in the wall
- The glazing covered by insulation during evening and dampers closed to prevent heat loss.
- Thermal storage provides a time delay between absorption of solar energy on the outside wall and delivery to the interior.

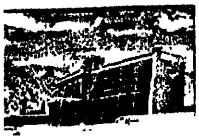


Proves to be uneconomical and eats up space

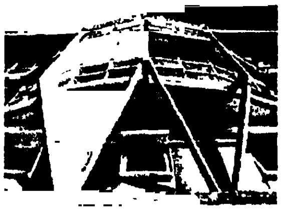
Indirect gain systems

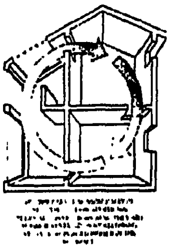
Room	Average Temp. (°C)	Min. Temp. (°C)	Max. Temp. (°C)
Half Trombe	7.9	2.8	17.0
Unvented Trombe	13.2	9.1	18.9
Vented Trombe	13.2	8.1	18.8
Direct Gain	7.0	0.3	23.3
Outside Air	-8.3	-16.6	1.2

Basic construction:
12 inches thick adobe/stone wall, and 6mm thick glass



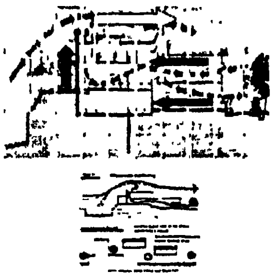
Sunspaces





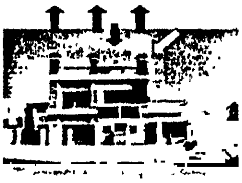
- **Cooling**
  - Ventilation
  - Solar chimney
  - Wind tower
  - Earth tunnel
  - Earth berm
  - Evaporative cooling

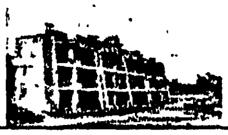
Passive cooling techniques- Ventilation



- Creates air movement by 'push-pull' effect of positive air pressure on the windward side and suction from the leeward side.
  - Windows (locations, sizes on opp faces, shading, internal partitions)

Solar chimney

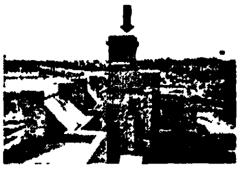


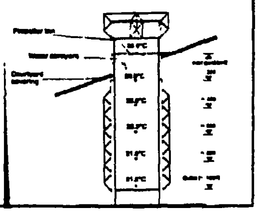


- Uses stack effect, but chimney deliberately heated by solar radiation.
- Space detached from the main building.
- Advisable for regions with low wind speed.
- Could be roof or wall integrated.
- Could be coupled with other natural conditioning systems

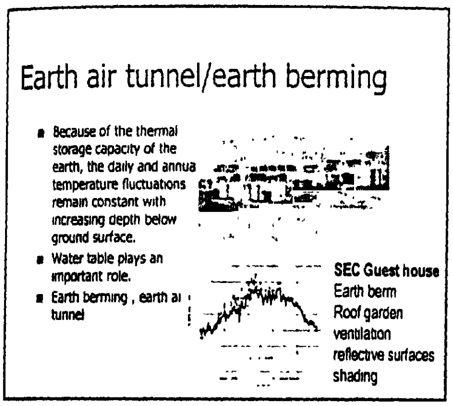
Solar chimney at the Retreat

Wind tower





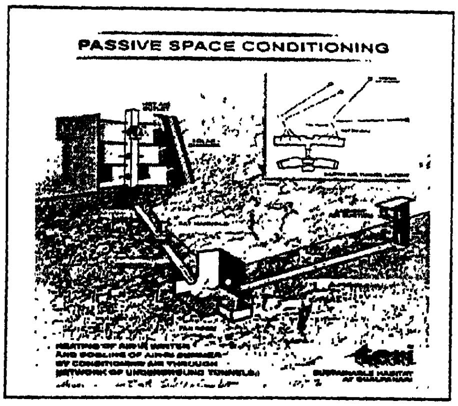
- Daytime- outside air enters through the openings, gets cooled, becomes heavier ,sinks down and into the rooms and vented out through the windows
- Nighttime-the tower warms up, draws in cooling air through the windows and creates upward draught.



Earth air tunnel/earth berming

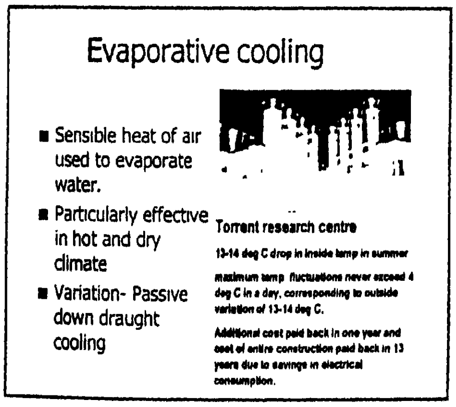
- Because of the thermal storage capacity of the earth, the daily and annua temperature fluctuations remain constant with increasing depth below ground surface.
- Water table plays an important role.
- Earth berming , earth ai tunnel

SEC Guest house
Earth berm
Roof garden
ventilation
reflective surfaces
shading



PASSIVE SPACE CONDITIONING

HEATING OF AIR IN WINTER
AND COOLING OF AIR IN SUMMER
BY CONDITIONING AIR THROUGH
(NETWORK OF UNDERGROUND TUNNELS)
SUSTAINABLE HABITAT
AT GUALPAHARI



Evaporative cooling

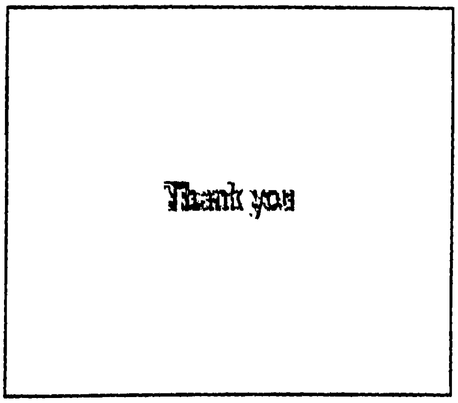
- Sensible heat of air used to evaporate water.
- Particularly effective in hot and dry climate
- Variation- Passive down draught cooling

Torrent research centre

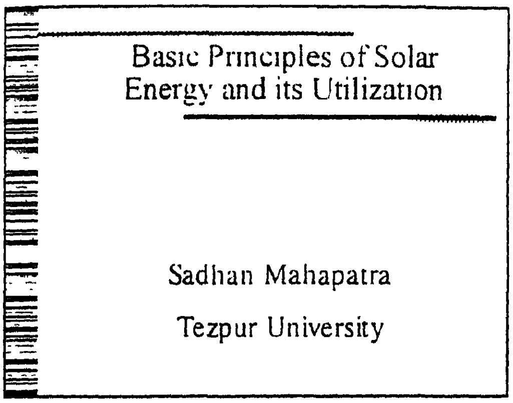
13-14 deg C drop in inside temp in summer

maximum temp fluctuations never exceed 4 deg C in a day, corresponding to outside variation of 13-14 deg C.

Additional cost paid back in one year and cost of entire construction paid back in 13 years due to savings in electrical consumption.



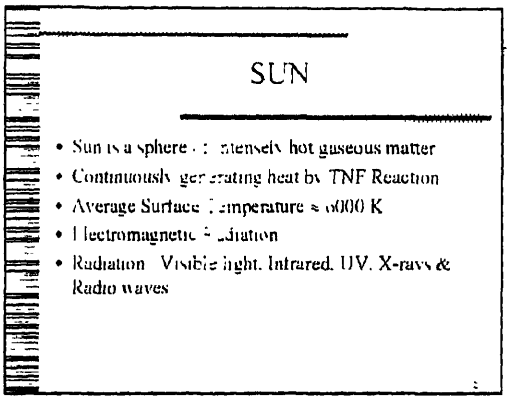
Thank you



Basic Principles of Solar Energy and its Utilization

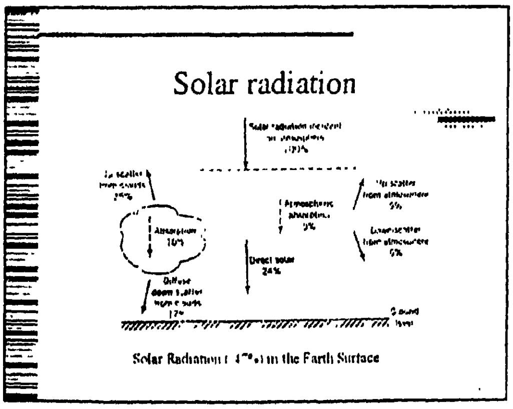
Sadhan Mahapatra

Tezpur University



SUN

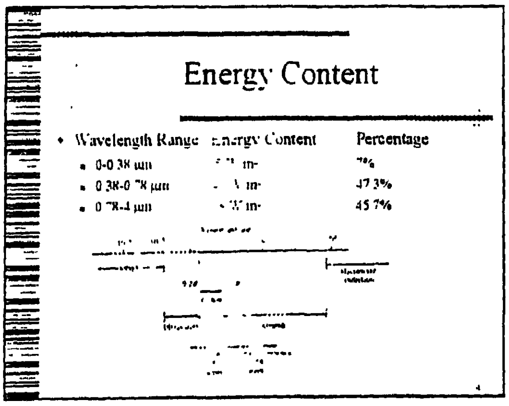
- Sun is a sphere of intensely hot gaseous matter
- Continuously generating heat by TNF Reaction
- Average Surface Temperature ≈ 6000 K
- Electromagnetic Radiation
- Radiation : Visible light, Infrared, UV, X-rays & Radio waves



Solar radiation

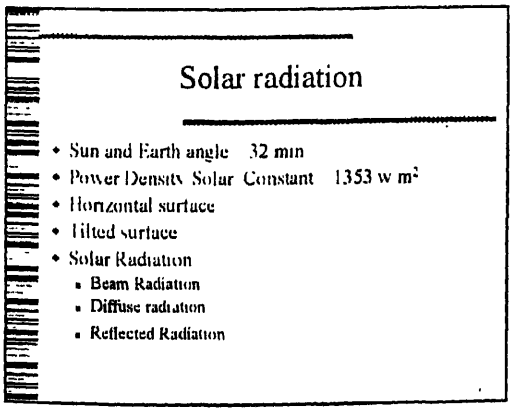
Solar radiation incident on atmosphere
100%
Back scatter from clouds
25%
Absorption
10%
Atmospheric absorption
9%
Up scatter from atmosphere
5%
Down scatter from atmosphere
5%
Direct solar
24%
Diffuse down scatter from clouds
17%
Ground level

Solar Radiation (47%) on the Earth Surface



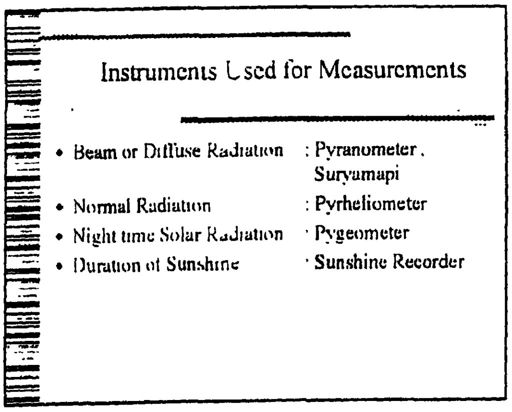
Energy Content

- Wavelength Range Energy Content Percentage
  - 0-0.38 µm [illegible] [illegible]
  - 0.38-0.78 µm [illegible] 47.3%
  - 0.78-4 µm [illegible] 45.7%



Solar radiation

- Sun and Earth angle 32 min
- Power Density Solar Constant 1353 w m^{2}
- Horizontal surface
- Tilted surface
- Solar Radiation
  - Beam Radiation
  - Diffuse radiation
  - Reflected Radiation



Instruments Used for Measurements

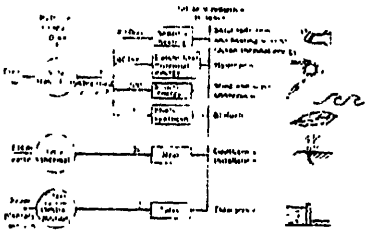
- Beam or Diffuse Radiation : Pyranometer, Suryamapi
- Normal Radiation : Pyrheliometer
- Night time Solar Radiation : Pygeometer
- Duration of Sunshine : Sunshine Recorder

Solar Radiation

- Average Solar Insolation in India 5 kW m² day
- Average Bright sunshine : 250-300 days

State Capital	Solar Radiation (kWh/m²/day)
Guwahati	5.2
Agartala	5.3
Shillong	4.6
Kohima	4.6
Imphal	4.8
Aizawl	4.7
Itanagar	4.6

Solar Energy

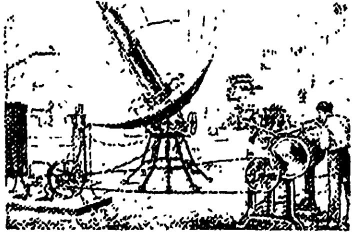


Natural Energy currents on Earth (terawatts)

Solar Energy Utlization

- Solar Thermal application
  - Low Temp application
    - Collector
  - High temp application
    - Concentrating
- Solar Photovoltaic application
  - Solar Energy directly converts to electricity (DC)
    - Solar Cell

Abel Pifre's Solar Powered Printing Press (France. 1870-1880)



Solar Thermal Application

- Passive solar house Heating or Cooling
- Water heating
- Solar air heaters
- Solar Desalination
- Solar concentrators
- Solar Thermal electric power plant

SPV Applications

- Stand alone systems
  - Lighting
    - Solar Lantern
    - Solar Domestic Lighting systems
    - Solar Street light etc
  - Power supply to irrigation telecommunications etc
- Grid connected systems

Utilization of Solar Energy in Buildings

Introduction

All buildings have a primary function to enclose space to provide an internal environment, suitable for habitation. This in turn requires provision of comfort conditioning and other allied services. Essentially, then, in cold periods, the need is to collect and store heat (or thermal energy) for distribution whenever and wherever required. Similarly, in warm periods the need is to avoid overheating from direct solar radiation or unwanted internal heat gains from appliances and people, and to dissipate heat by natural ventilation or by other means of natural cooling.

The long-term objective is to reduce building energy loads in a cost-effective manner such that renewable sources of energy can meet and exceed energy demands in the building. The first step is the reduction of loads through passive solar, climate-sensitive strategies. Remaining loads may then be met by other renewable resources, such as solar energy.

Sunlight—solar energy—can be used to generate electricity, provide hot water, and to heat, cool, and light buildings. Solar energy can be employed in number of ways in buildings to accomplish the aforementioned tasks. Buildings can have their heating and cooling needs met by Sun in two ways: 'Passive' or 'Active'. Passive solar architecture relies on the design or architecture of the building to ensure climate control, through natural conduction, convection, and radiation. Active solar features use other sources of energy as well.

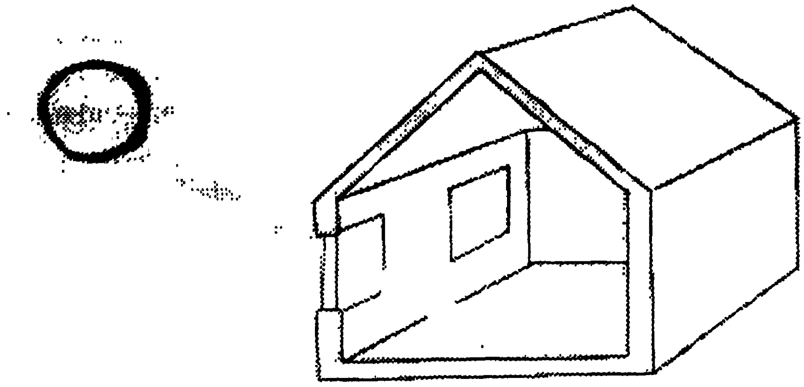
Thus, passive solar design can cost effectively provide space heating; photovoltaics can supply auxiliary electricity; solar thermal systems can provide energy for heating water for domestic use or for space heating; and transpired solar collectors can preheat air for a building's ventilation system.

Passive Solar Features

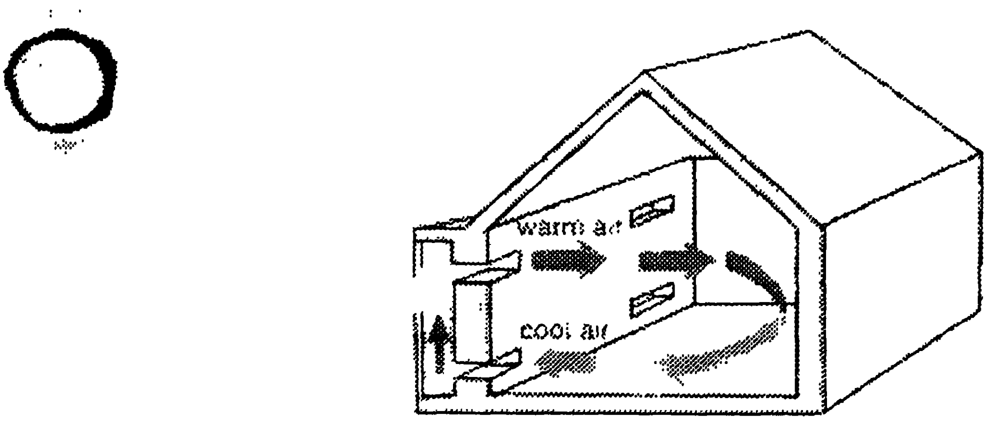
Buildings designed for passive solar and daylighting incorporate design features such as large south-facing windows and building materials that absorb and slowly release the sun's heat. No mechanical means are employed in passive solar heating. Incorporating passive solar designs can reduce heating bills as much as 50 percent. Passive solar designs can also include natural ventilation for cooling.

In cold climates, south-facing windows designed to let the sun's heat in while insulating against the cold are ideal. In hot and moderate climates, the strategy is to admit light while rejecting heat. Interior spaces requiring the most light, heat, and cooling are located along the south face of the building, with less used space to the north. Open floor plans allow more sun inside.

The simplest passive design is the direct gain system in which the sun shines directly into a building, heating it up. The sun's heat is stored by the building's inherent thermal mass in materials such as concrete, stone floor slabs, or masonry partitions that hold and slowly release heat. With indirect gain systems, thermal mass is located between the sun and the living space.



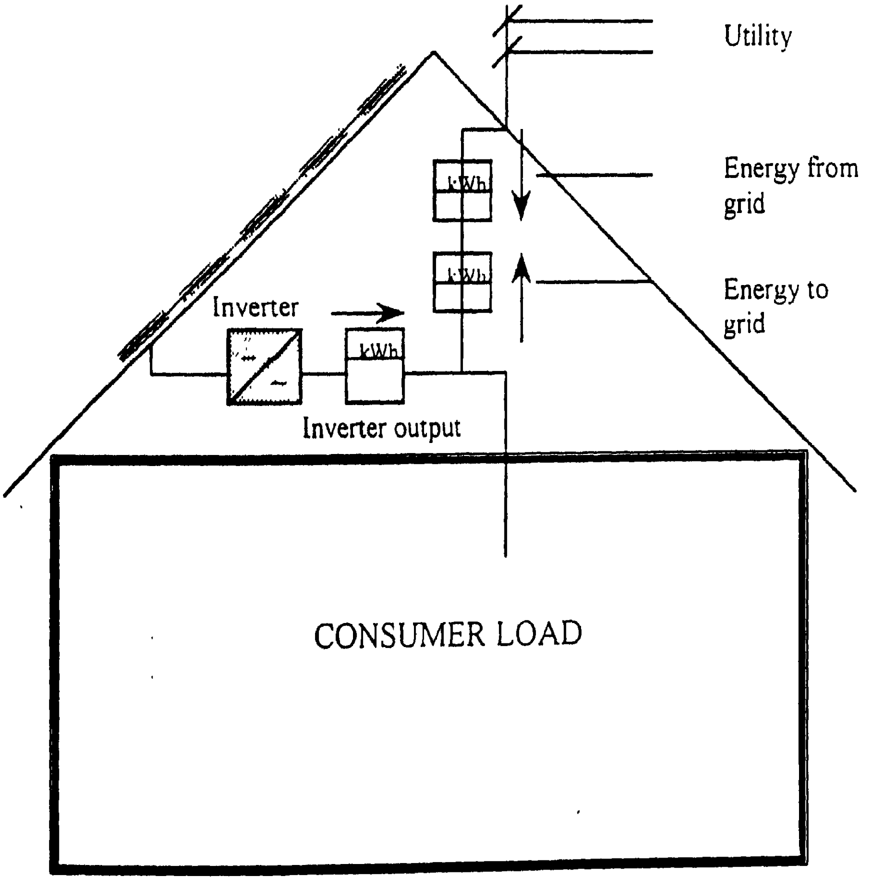
Trombe wall is one of these devices. A Trombe wall consists an 8- to 16-inch thick masonry wall coated with a dark, heat-absorbing material and covered by a single or double layer of glass, placed from about 3/4" to 6" away from the masonry wall. Heat from the sun is stored in the air space between the glass and dark material, and conducted slowly to the interior of the building through the masonry. Adding a Trombe wall and south-facing windows is an easy way for a home to take advantage of solar heat.



South-facing sunrooms are often added on as a way to retrofit a home to take advantage of the sun's heat and light. It is also possible to use a sunroom to help ventilate the rest of the house. Lower vents from the sunroom to the interior rooms draw air through the living space to be expelled out the upper vents to the outside along the top of the sunroom.

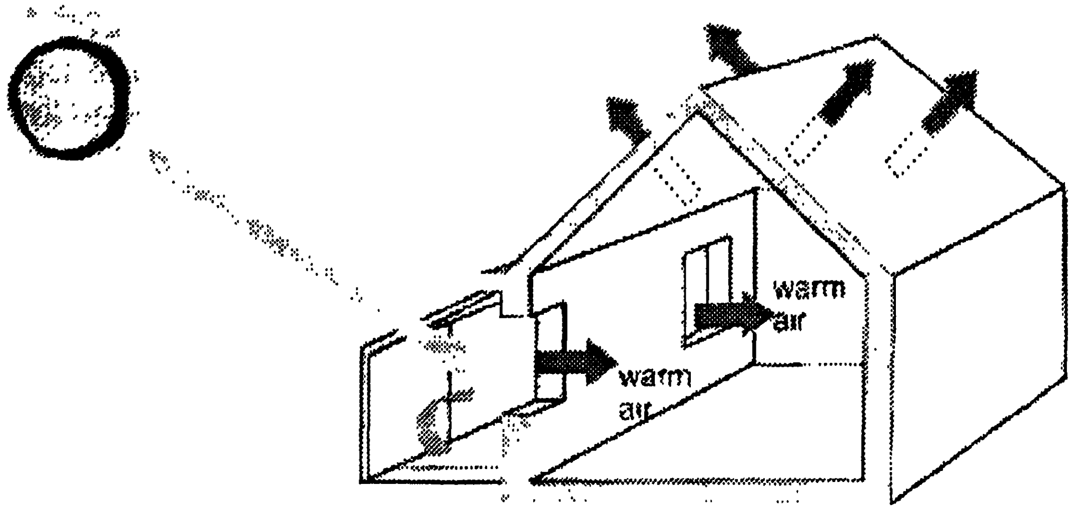
Many passive solar designs include natural ventilation for cooling. One of passive solar cooling devices is the *thermal chimney*, which can be designed like a smoke chimney to vent hot air from the house out through the roof. A thermal chimney employs convective currents to draw air out of a building. By creating a warm or hot zone with an exterior exhaust outlet, air can be drawn into the house ventilating the structure.

Photovoltaics are particularly useful for helping to meet peak cooling loads in buildings, since their power output reaches a maximum at midday, when cooling loads are greatest. The best strategy when considering a PV system is to integrate it into the initial design of the building. Building-integrated photovoltaic materials are manufactured with the double purpose of producing electricity and serving as construction materials. They can replace traditional building components, including curtain walls, skylights, atrium roofs, awnings, roof tiles and shingles, and windows.



PV systems can also be easily retrofitted onto existing buildings, on rooftops, on added awnings, on solariums, or on nearby land, if it is available.

PV could be used to power emergency lights, outdoor lights, and swimming pools etc. In fact, now solar-charged detection circuits are available that automatically turns on the light when triggered by heat or motion, then turns off once the movement is stopped.



Passive solar heating is best incorporated into a building during the initial design. The whole building design approach evaluates passive solar heating/cooling in the context of building envelope design (particularly for windows), daylighting, and heating and cooling systems. Window design, and glazing choices in particular, are critical factors for determining the effectiveness of passive solar heating. In cooler climates, large south-facing windows are used, as these have the most exposure to the sun in all seasons.

Solar Photovoltaics

Photovoltaic (solar cell) systems convert sunlight directly into electricity. A solar or PV cell consists of semiconducting material that absorbs the sunlight. The solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. PV could be used in buildings, either as stand-alone or grid-connected systems.

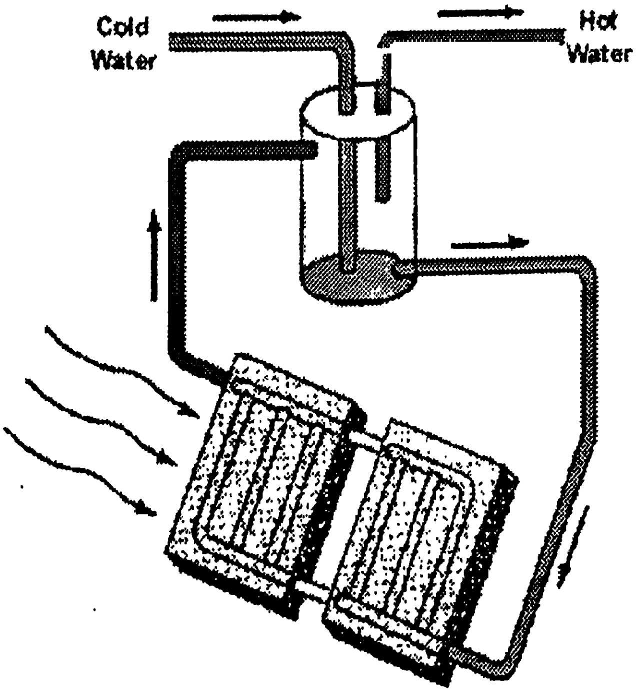
Stand-alone systems are those with no connection to the utility grid. A stand-alone residential system consists of solar panels, a battery to store power for use at night, and a device called an "inverter" to allow conventional appliances to be powered by solar electricity. Batteries are relied on to store power for use at night and during periods of limited sun. Using PV systems instead of generators is now an affordable alternative on residential and commercial buildings in remote locations. Where utility power is available, a grid-connected PV system can supply some of a building's electricity needs. Surplus electricity is exported to the utility's grid, then is bought back when the building's PV system is not producing electricity. This arrangement allows the system to use the utility as a back-up supply in place of batteries.

Solar Thermal

Solar thermal systems use the heat of the sun to provide hot water for domestic uses and for heating swimming pools etc. Solar water heating systems for buildings have two main parts: a solar collector and a storage tank. The solar collector works on the principle of greenhouse effect wherein short-wave solar energy (sunlight) is collected through glazing and the long wave radiation (heat energy) is prevented by the glazing from leaving the enclosure.

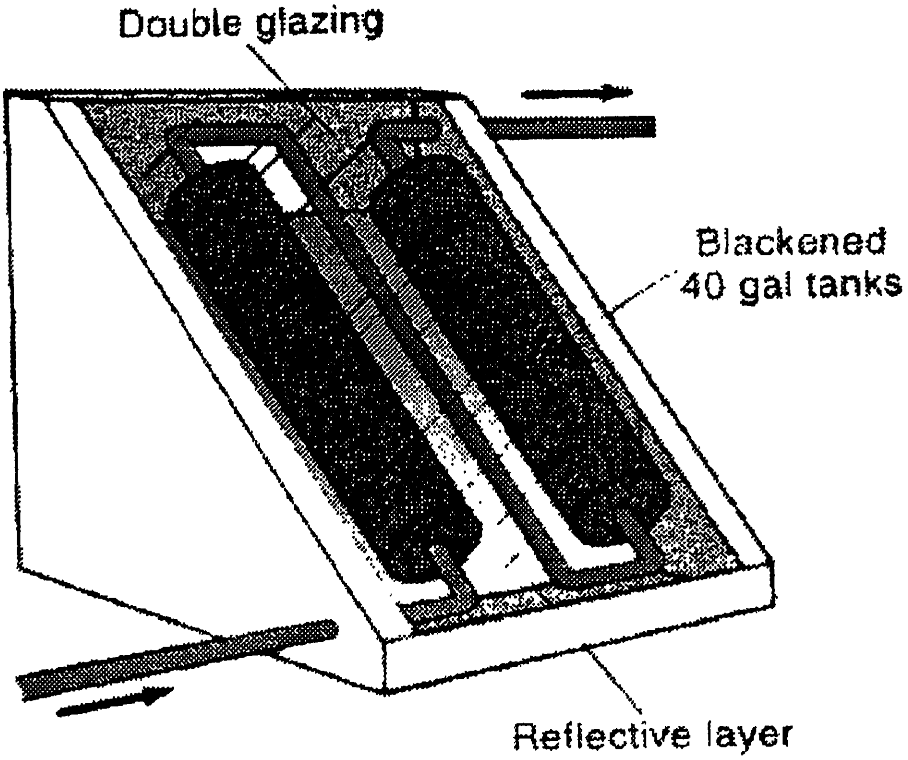
A flat-plate collector is a large, shallow box—typically mounted on a roof—which heats water using the sun's energy. A typical flat-plate collector is a metal box with a glass or plastic cover (or glazing) on top and a dark-colored absorber plate on the bottom. The sides and bottom of the collector are usually insulated to minimize heat loss. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar energy into heat energy. The heat is transferred to water passing through pipes attached to the absorber plate. Absorber plates are commonly painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are usually made of metal—typically copper or aluminum—because the metal is a good heat conductor. To move the heated fluid between the collector and the storage tank, a system either uses a pump (*active* system) or gravity (*passive* system), as water has a tendency to naturally circulate as it is heated.

An active system is one where the exchange fluid is actively pumped from the storage tank through the collectors and back into the tank. An electronic controller, a pump, valves and other components are needed for its operation. The passive solar water heater is known by many names; Thermo siphon Systems, Batch Heater or Breadbox are the most common.



Thermo siphon System

Thermo siphon Systems use the natural tendency of heated water to rise and cooler water to fall to perform the heat collection task. As the sun shines on the collector, the water inside the collector flow-tubes is heated. As it heats, this water expands slightly and becomes lighter than the cold water in the solar storage tank mounted above the collector. Gravity then pulls heavier, cold water down from the tank and into the collector inlet. The cold water pushes the heated water through the collector outlet and into the top of the tank, thus heating the water in the tank.

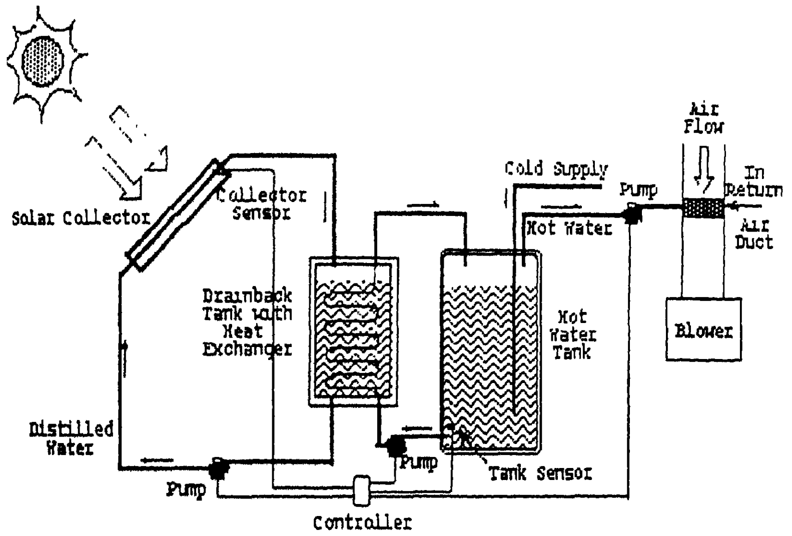


Batch type water heater

Batch water heaters, also known as 'breadboxes' are very simple passive systems for heating water using solar energy and have been used since the early 1900's. Batch systems consist of black storage tanks contained within an insulated box that has a transparent cover. Cold water is added to the hot water stored in the tanks whenever hot water is removed.

Systems that use fluids other than water in the collector's tubes usually heat the water by passing it through a coil of tubing in the tank.

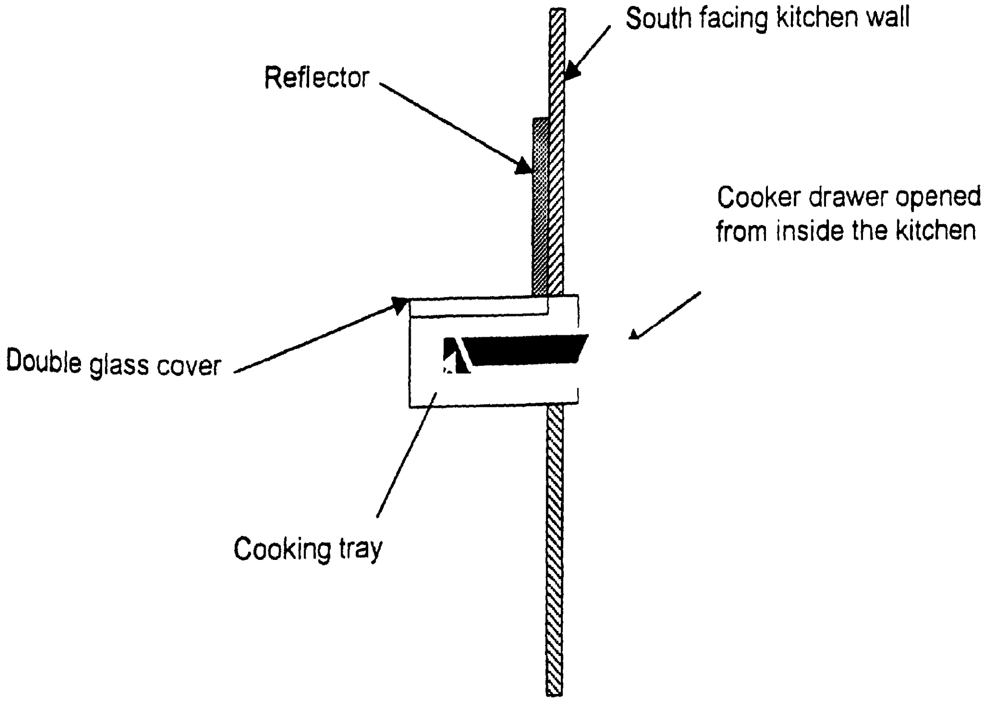
Many large buildings can use solar collectors to provide more than just hot water. Solar process heating systems can be used to heat these buildings.



Solar space heating

Solar swimming pool heaters are one of the simplest methods of solar heating. Large areas of solar collectors are positioned on the roof. Pool water is pumped through the collector, gaining heat as it travels through the collectors' piping.

In addition to aforementioned applications, solar thermal energy can also be used for cooking purposes. The box cooker, which is the simplest and the cheapest solar cooker type,


South facing kitchen wall
Reflector
Cooker drawer opened from inside the kitchen
Double glass cover
Cooking tray

Building integrated solar cooker

consists of an insulated box with a double glass cover. This cover acts as a solar energy trap by exploiting the greenhouse effect. Solar radiation passes through the glass cover, and is absorbed by the walls, the bottom of the cooker and the cooking utensils. The darker the pots and the inside of the cooker are, the better they are heated. To maximize the heating effect, the cooker's walls, and the outer side of the cooking pots are painted black. To increase the incoming solar radiation, reflector, such as mirror, is used. With innovative designs, it is possible to integrate solar cooker with the kitchen itself, provided kitchen wall is south facing.

Ventilation Preheating

A solar ventilation system can be used in cold climates to preheat air as it enters a building. Ventilation preheating systems, also known as transpired solar collectors, are ideal for buildings with large ventilation (including corridor ventilation for high-rise apartments) requirements. The transpired solar collector is a simple concept. It comprises a metal sheet; perforated (with numerous tiny holes) and painted black or some other dark color that fits the building design. This sheet is mounted on a sunny, south-facing wall, leaving space between the main building wall and the metal. A fan is used to suck air through the tiny holes. The dark metal absorbs the solar heat. The fan pulls the fresh air into the plenum, heating it and drawing it into the building's ventilation system.

Conclusions

The up-front installation costs of solar systems can be relatively expensive. But this cost is quickly attenuated by the fact that the systems use no fuel and require little maintenance. Although the actual economics of installing a solar system depend on many variables and on local conditions; in terms of life-cycle costs, solar thermal systems are very attractive. Besides, in last few years, solar systems have taken great strides in terms of versatility, quality, and reliability. Therefore, now there exists a strong case for incorporating `solar' in to building-design.

Photovoltaic- a short description

Photovoltaic (PV) technology based on solar cells provides one of the most environmentally friendly routes for generation of electricity. Solar cells are semiconductor devices, which convert sunlight into electricity directly without involving any moving parts. This is done by utilizing the electrical properties of natural materials when they are exposed to sunlight.

A short overview of its development

Becquerel in 1839 discovered the development of Photovoltage when light was directed onto one of the electrodes in an electrolyte solution. In 1877, Adams and Day observed the Photovoltaic (PV) effect in selenium. Early solid-state researchers including Lange, Grondahl and Shottky did pioneering work on selenium and cuprous oxide solar cells. In the year 1954, research results were published in scientific literature on the use of PV effect for energy conversion. In 1958, the first solar powered satellite was sent to the orbit. Solar cells satisfied the requirements of long- lasting and light-weight power sources for space applications. In addition, they worked most efficiently in uninterrupted sunlight available in outer space.

Although solar cells were extensively used for power generation in space applications, their use in terrestrial applications started only after the oil crisis of the seventies. Since then, PV has posted impressive growth on all fronts. Technologically, conversion efficiencies of PV module have improved from 8-9% in 1980 to 14% currently. During the same period, costs per peak watt have come down from US$25 to US$ 4. Simultaneously, global market has to 278 MWp annually with the aggregate market nearing more than 1GWp. The structure of the market has also changed from early demonstration projects which focussed on the promotion of technology, to a current approach where the emphasis is on product and applications, and consequently on payment for services. Today the technology is considered one of the safest and most reliable alternate power generation technologies that can be used for a variety of applications in different modes.

About the Technology

PV Devices

The fundamental power unit of a PV system is the solar cell, which is an electrical device, made of semiconductor material. Each cell or a PV device has minimum two layers of dissimilar semiconductor material that create an electromotive force at their junction. The cell works by pushing free electrons generated by Photons of incident radiation due to this force. Different types of semiconductors can be used in a variety of physical states viz; single crystal, polycrystalline or amorphous/thin films to fabricate solar cells.

Crystalline silicon (single or multi-crystalline wafers) is the most common semiconductor material used in PV devices. It has the longest history and strongest technology base, and it still dominates the global PV market. The choice of PV material is driven by two factors viz; higher sunlight to electrical conversion efficiency and low processing cost ultimately leading to overall cost reduction in PV systems. Although crystalline devices are generally more efficient, thin-film devices compete with them for their lower cost. In addition, there are valid concerns about the availability of high-grade material at suitable prices to meet the growing PV market by crystalline silicon alone despite the fact that silicon is abundant in nature. Thin- film technology where a very thin layer of PV material is deposited over a substrate, is increasingly regarded as the preferred

This approach is preferred over the cost-benefit analysis approach because the later depends upon assigning a monetary value to the benefits of each system. In the case of PV, benefits are often social in nature and hence it may be difficult to quantify the economic returns.

To give an example of comparing PV with diesel generator using life-cycle costing, one has to consider the analysis period of 20 years because the life of PV modules is 20 years. Life of the diesel generator might last only 10 years. In addition to the initial cost (which is high for PV), one must calculate the cost of replacing diesel generator after 10 years, and 20 years worth of fuel which must be included in the diesel option. The costs of maintenance and repair for the two systems over the whole 20 year cycle should also be included to determine the better option.

Presently, there are hidden and direct subsidies available to fossil fuels. Kerosene is subsidized in most developing countries. Transmission and distribution losses, cost for replacement of the plant etc. are not considered. As a result, there is little incentive for any private or public sector to invest in energy source if cheaper options are available. To have an unbiased comparison between PV and other conventional energy supply options, real costs of all type of energy generation must be available. In addition, all externalities such as environmental degradation, resource depletion, wealth creation etc. should be considered.

Government policy

The policy on SPV is clearly directed towards a greater thrust on all aspects of SPV technology and applications. The recent policy measures provide excellent opportunities for increased investment in this sector, technology upgradation, induction of new technologies, market development and export promotion. MNES provides a capital subsidy of up to 50% of the ex-works cost of certain systems covered under demonstration and utilization programme. Table 2.2 gives a pattern of financial assistance for the 1999-2000 programme.

Besides the subsidies, there are a host of benefits available to both manufacturers and users of PV systems. These are:

- 100% depreciation for tax purposes in the first year of the installation of the systems;
- no excise duty on manufacturers of most of the finished products;
- low import tariffs for several raw materials and components; and
- soft loans (2.5%-7.5%) to users, intermediaries and manufacturers

Pattern of financial assistance on SPV systems

	SPV System	Approx. cost (in Rs)	Central Subsidy	Service charge (Rs)
1	Solar Lantern	4 000	Rs 1500 /- (fixed)	100
2	Solar Home System	12 000	Rs 6,000 or 50 % of ex-works cost, whichever is less	200
3	Street Lighting System	24 000	Rs 12,000 or 50 % of Ex-works cost whichever is less	
4	Power Plants & Other systems	3 – 4 lac per kW_p	Rs 2,00,000 / kWp of PV array capacity or 50 % of Ex-works cost, which ever is less	10 000
5	PV water pumping systems	200 per Wp	Rs 125 per Wp of PV array used , subject to a maximum of Rs 2,50,000 per system	

Solar Photovoltaics

by

Debajit Palit

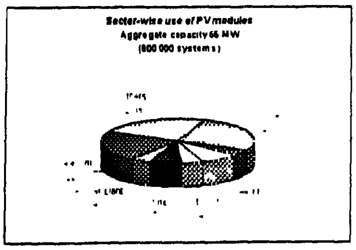
TERI North Eastern Regional Centre

- ✓ **Overview of the sector**
- ✓ **What is Photovoltaics**
- ✓ **Photovoltaics in buildings**
- ✓ **Economics of PV**

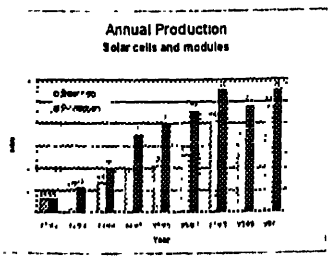
Part I

Overview of the sector

Sector-wise use of PV modules in India



Industrial production in India



Top PV Cell/Module Producers of 1999/2000

Company	Production (MW)		Rank
	1999	2000	2000
BP/Amoco Solarex	32.5	41.0	3.0
Kyocera	30.3	42.0	2.0
Sharp	30.0	50.4	1.0
Siemens Solar	22.2	28.0	4.0
Astropower	22.0	18.0	5.0
Sanyo	13.0	17.0	6.0
Photowatt	10.0	14.0	7.0
ASE (GmbH)	[illegible]	12.0	8.0
Total	160.0	222.4	

Technologies and their efficiencies

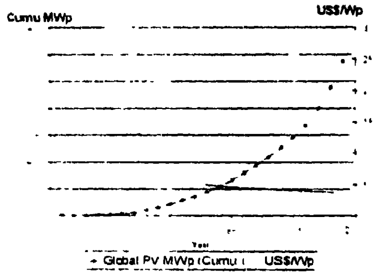
Efficiency (%) status and forecast

Cell technology	Manufactured eff for Cell	Laboratory eff for Cell	1998 Module eff	2000 Module eff	2010 Module eff
Single crystal silicon	15.1 17.5	[illegible]	14-16	[illegible]	22
Polycrystalline silicon	13.5 15	[illegible]	13-15	[illegible]	20
Amorphous silicon	5 7	[illegible]	6-8	[illegible]	14
Concentrator cells	24	[illegible]	18	[illegible]	30
Silicon film	9 11	[illegible]	8-10	12	15
Ribbon sheets			14	12	21
CIS			7-8	12	14
CdTe			7-8	12	14

PV module manufacturing cost: Status and forecast

Cell technology	1997 price	2000 cost/price	2010 cost/price
Single X'tal Silicon	3.90-4.25	1.50/2.00	1.20 2.00
Polycrystalline Silicon	3.90-4.25	1.50/2.00	1.20 2.00
Ribbon (sheet)	3.90-4.25	1.50/2.00	1.20 2.00
Concentrators (includes trackers, electronics)	6.00	1.80/2.30	0.50 1.33
Amorphous Silicon	2.50-4.50	1.20/2.00	0.75 1.25
Copper indium diselenide (CIS)	-	1.20/2.00	0.75 1.25
Cadmium telluride (CdTe)	-	1.20/2.00	0.75 1.25
Silicon film on low cost substrate	-	1.20/2.00	0.75 1.25

Market volume & cost trends



Part II

What is Photovoltaics

Definition

Technology by which radiant energy of the sun is converted to direct current electricity

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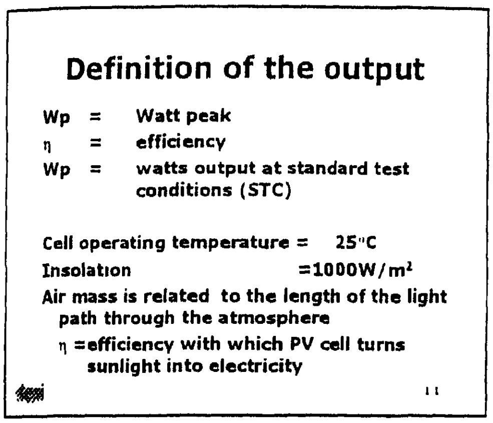
Genesis

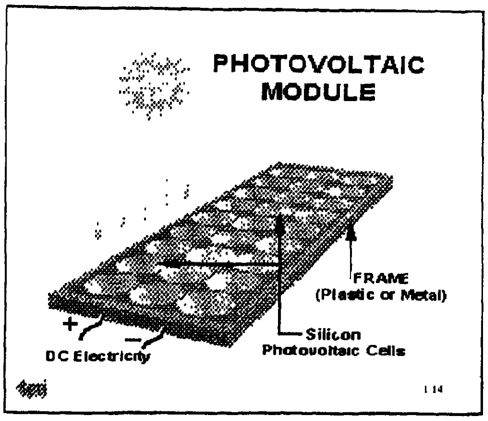
- Discovered in 1839 by Becquerel
- First research results published in 1954 on the use of PV effect for energy conversion
- PV Cells made their debut in 1958 in USA for use in Vangaurd satellite



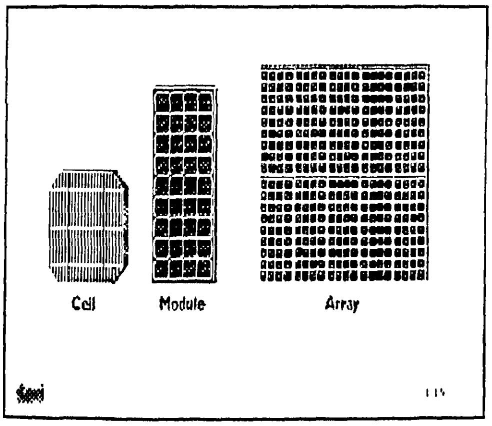
Definition of the output

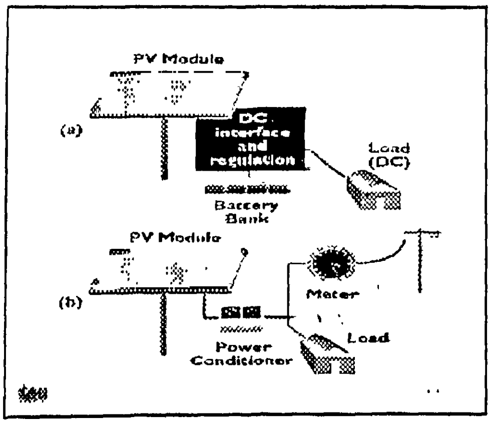
Wp = Watt peak
η = efficiency
Wp = watts output at standard test conditions (STC)

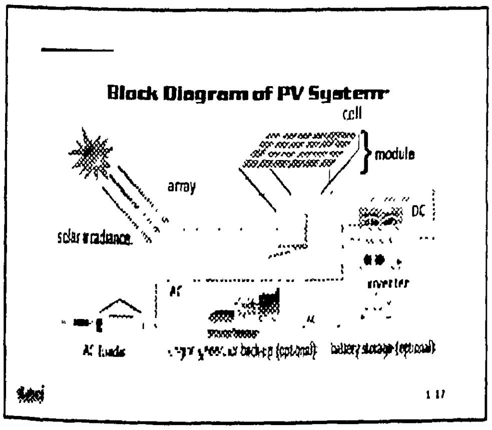
Cell operating temperature = 25°C
Insolation =1000W/m^2
Air mass is related to the length of the light path through the atmosphere
η =efficiency with which PV cell turns sunlight into electricity



PHOTOVOLTAIC MODULE

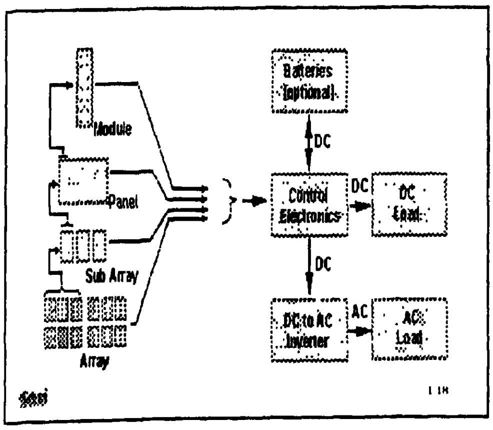






Block Diagram of PV System

cell
module
array
solar irradiance
DC
inverter
AC
AC
AC loads
engine generator back-up (optional)
battery storage (optional)



Part III

Photovoltaics in buildings

Why Photovoltaics?

- Photovoltaics in building is worth considering if,
  - The building has access to solar radiation
  - Innovative design adoption are preferred
  - Building is energy efficient by design
- Traditionally, photovoltaic (PV) arrays are mounted on special support structures. However, they can also be mounted on buildings, or even be made an integral part of the building envelope. From an architectural point of view, PV in buildings today

... contd

- Does not require any extra land area for installation
- Can provide electricity during peak time thus reduce the utility's peak delivery requirements, or in a decentralized mode, can store the electricity in a battery for use at any time of the day
- may replace conventional building materials and thus serve the dual role which enhances payback considerations
- Can provide an improved aesthetic appearance in an innovative way

•PV could be used in buildings, either as stand-alone or grid-connected systems

•PV systems can be easily retrofitted onto existing buildings, on rooftops, on added awnings, on solariums, or on nearby land, if it is available.

Stand-alone PV

- Stand-alone systems are those with no connection to the utility grid.
- A stand-alone residential system consists of:
- Solar PV panels
- Battery to store power
- An "inverter" to allow conventional appliances to be powered by solar electricity

Grid-connected PV

In a grid-connected PV system

- Surplus electricity is exported to the utility's grid
- The utility-grid is used as a back-up supply in place of batteries.

PV applications

PV could be used to power

- Emergency lights
- Outdoor lights
- Swimming pools lighting etc.

Design process

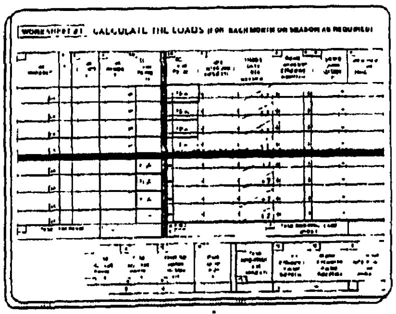
Screening of site, applications, & buildings

Building envelope performance requirements

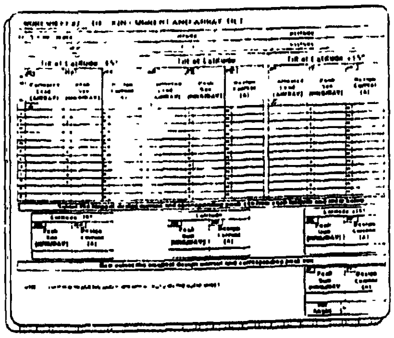
- Weather condition requirements
- structural requirements
- Occupant requirements
- Town planning and design requirements
- Emissions requirements
- Enclosure requirements

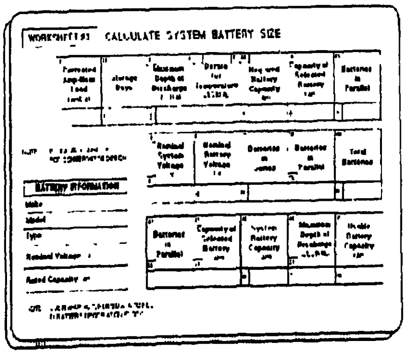
Basic integration requirements

- design of the building (Shape, size orientation, colour)
- Mechanical integration (multifunctionality of a PV element)
- Electrical integration (battery storage/grid interaction)
- Operation and maintenance integration (O&M for PV must be integrated with building maintenance and control)

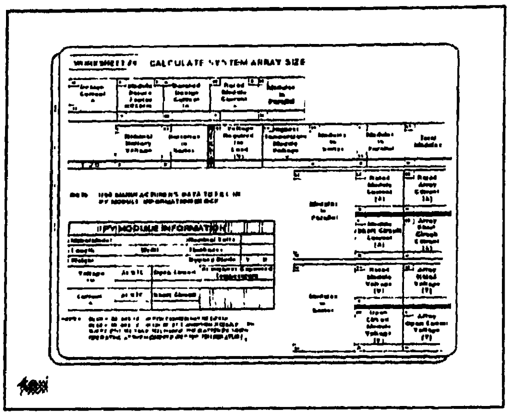


WORKSHEET #1 CALCULATE THE LOADS (FOR EACH MONTH OR SEASON AS REQUIRED)





WORKSHEET #3 CALCULATE SYSTEM BATTERY SIZE



WORKSHEET #4 CALCULATE SYSTEM ARRAY SIZE

PV MODULE INFORMATION

Total load requirements of example household

Unit	Number	Wattage (W)	Usage (hours/day)	Load (Wh)
CFL	2	11	5	110
CFL	1	9	3	27
TV	1	18	5	90
Fan	1	20	8	160
Total Load (Wh/day)				387

Define systems losses

Battery 80%
Change controller 90%
Mismatch factor 85%

$$\text{Array load} = \frac{\text{Total daily load (Wh/day)}}{\text{Battery efficiency} \cdot \text{Charge regulator efficiency}}$$

$$\text{Array size} = \frac{\text{Array load}}{\text{Insolation} \cdot \text{Mismatch factor}}$$

Example For the total daily demand of 387 Wh (of the example household), the array load and the array size is as follows

$$\text{Array load} = \frac{\text{Total daily load (Wh/day)}}{\text{Battery efficiency} \cdot \text{Charge regulator efficiency}}$$

$$\text{Array load} = \frac{387}{0.8 \cdot 0.9} = 538 \text{ Wh/day}$$

$$\text{Array size} = \frac{\text{Array load}}{\text{EHFS} \cdot \text{Mismatch factor}}$$

$$\text{Array size} = \frac{538}{5.2 \cdot 0.85} = 129 \text{ W}_p$$

$$\text{Battery capacity} = \frac{\text{Daily load (Wh)} \cdot \text{Reserve back-up}}{\text{Nominal voltage} \cdot \text{Maximum allowable discharge}}$$

Example If the daily load is 387 Wh (example household), then the number of batteries required for a system with two days reserve back-up will be

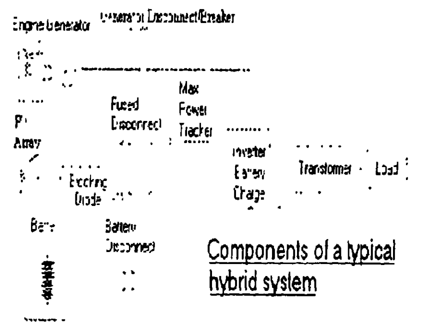
Load = 387 Wh
Reserve days = 2
Maximum allowable discharge = 50%

$$\text{Battery capacity} = \frac{\text{Daily load} \cdot \text{Reserve days}}{\text{Nominal voltage} \cdot \text{Maximum allowable discharge}}$$

$$= \frac{387\text{Wh/day} \cdot 2 \text{ days}}{12 \cdot 0.5}$$

$$= \frac{774 \text{ Wh}}{6}$$

Battery Capacity = 129 Ah



Components of a typical hybrid system

Integration of panels in the south facing roof

Part IV

Economics of PV

Economics of PV

- Economic validity of a project = cost benefit analysis
  - place a monetary value on all costs and benefits over a given period of time
  - for the project to go ahead, benefits need to be greater than the costs
  - method is relevant upon being able to assign a monetary value to benefits (social in nature)
- another approach is life-cycle costing; the initial costs and all future costs are considered for the entire operational life of a system.

An example of costs vs. benefits

System costs

- PV array
- support structure
- wiring material
- Design, installation labour
- Operation and maintenance
- Administrative costs
- price escalation rate
- Annual insurance premium
- Discount rate for borrowing money
- Loan Payment -down
- Loan payment - installment

System benefits

- Annual average daily energy
- Present selling price of electricity
- Discount rate for alternative investment benefits
- Improvement in local environment
- Improvement in global environment

Life Cycle Costing

$$LCC = C + M_{PW} + E_{PW} + R_{PW} - S_{PW}$$

Where, PW indicated the present worth of each factor

C = capital cost

M = maintenance cost

E = Energy cost (e g fuel cost)

R = replacement cost (e.g. battery)

S = salvage value

Thank you

for your attention and

for your interest in SPV

Solar water heating systems

Introduction

Solar energy is an inexhaustible source of energy. The solar constant, defined as radiation received on a unit area perpendicular to the direction of propagation of the radiation, at mean earth sun distance, is 1353 W/m². The actual radiation available on earth's surface is lower than the solar constant due to clouds as well as attenuation in atmosphere. The average availability of solar radiation in India varies from 4-6.5 kWh/m²/day dpending upon geographical location and season.

Though the solar energy is available easily and for 300 days in a year, there are limitations to its use. The main limitation is that it is a dilute source thus requiring larger area for collection. It is an intermittent source of energy thus storage is also essential. Thus the real challenge is to optimally design the solar water heating system.

Technology

Flat plate collector is the main and most important component of the solar water heating system. A flat plat collector is special kind of heat exchanger that transforms solar radiation energy in to heat. As shown in the figure 1 it consist of "black" absorber, a configuration of tube and plate, back insulation, top cover and casing.

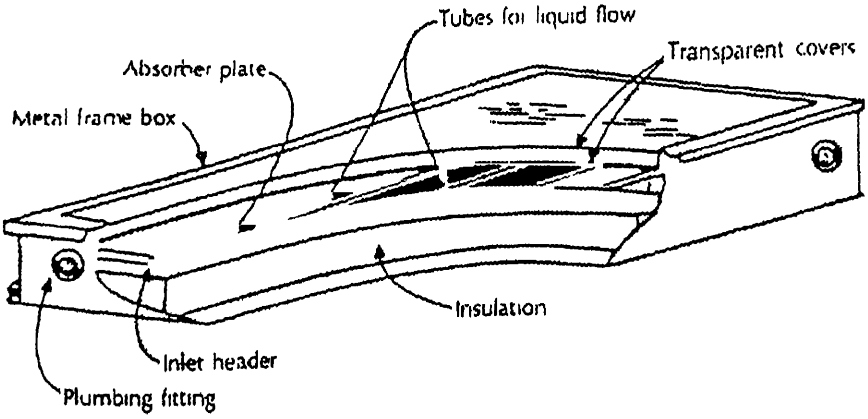


Figure 1 Schematic of flat plate collector

Solar radiation is absorbed by the absorber and transferred to the water flowing in the tubes. Providing thermal insulation on the backside of absorber reduces the heat losses. The heat gained by the water can be expressed as

$$Qu = F_R Ac [(\tau\alpha) G - U_L (Tf - Ta)] \text{-------------------}(1)$$

Where Qu - useful energy gain $\quad$ F_R - collector heat removal factor

Ac - collector area $\quad$ τ - Transmittance of glass

α - absorptance of the absorber plate $\quad$ G - Solar radiation incident on collector

U_L - collector overall heat loss coefficient

T_f - Water inlet temperature $\quad$ T_a - ambient temperature

Thus the efficiency of the collector is

$\eta = F_R A_c [(\tau\alpha) - U_L (T_f - T_a)/G]$ ---------------------(2)

The collector performance is measured by using this equation and presented in the form as shown in figure 2.

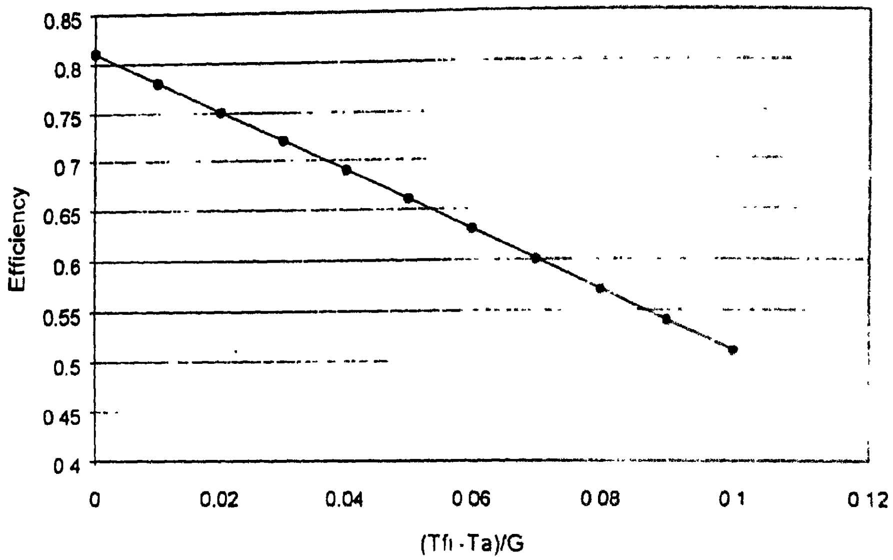


Figure 2 Flat plate collector efficiency curve

Types of systems

Depending upon the operation principle the solar water heating systems could be classified in to two broad categories.

Thermo syphon systems

This type of systems work on the principle of natural circulation. water in the collector is heated thus the density drops and the water becomes "lighter" and consequently it rises through the collector. This hot water is delivered in the hot water storage tank at the top level while as the cold water from the bottom of the tank flows to the collector. Hot water from the tank is removed from the top and cold water is added at bottom of the hot water tank. The thermo syphon systems up to 3000 liters per day (lpd) capacity have been installed.

Forced flow systems

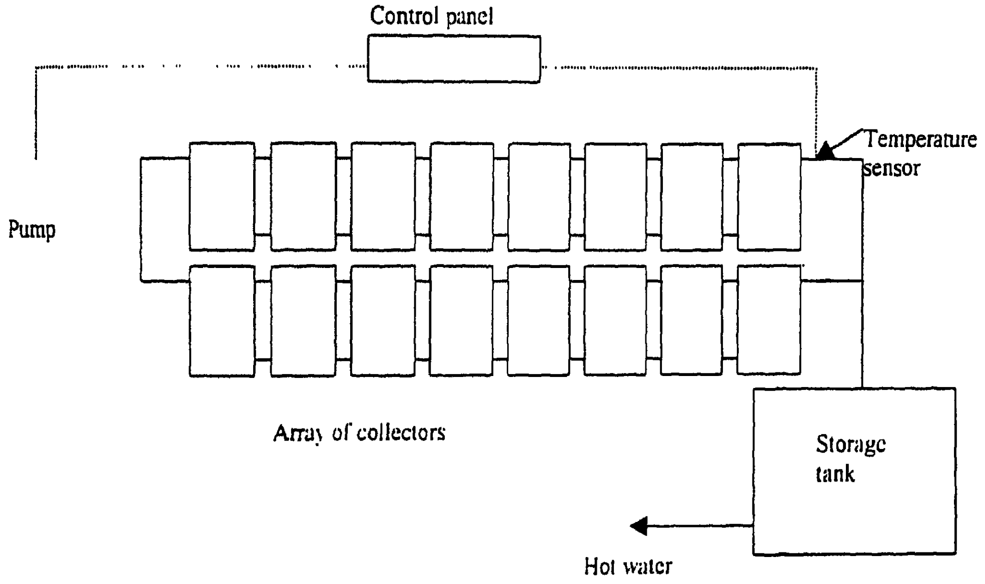
Majority of the systems installed in India is of open loop force flow type. As the capacity is higher large number of collectors are required and pump is used to circulate water through collectors. The pump is controlled by a temperature sensor installed at the end of collector array.

Designing

In case of domestic solar water heating systems thumb rule is used i.e. one south-facing collector for 100-125 lpd hot water requirements. In case of higher capacity systems eq. (2) along with the collector efficiency curve (figure 2) are used to design the solar water heating systems. The method generally followed by various manufacturers for designing solar water heating systems is discussed here. This method is an approximation. From the collector efficiency curve the factors $F'(\tau\alpha)$ (the y-axis intercept) and $F'U_L$ (slope) are estimated. Using equation 1 the area required for solar systems to meet the heating load L

$$A_c = L/\{F'(\tau\alpha)G - F_R U_L(T_{fi} - T_a)]\}$$

The load as well as the radiation incident on the collector varies during the year. Thus in case of higher capacity systems optimization of solar system size is critical.

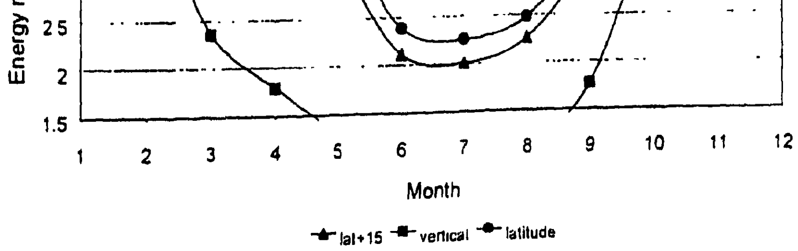


Further the radiation incident on solar collector depends upon the collector tilt angle. The radiation received in the inclined collector is estimated by using tilt factor where

$$G = \text{tilt factor} * I$$

Where G - radiation received on tilted surface & I -radiation on horizontal surface

The common practice is to keep tilt angel 15° more than the latitude with collector facing south. This is referred as "winter optimization" as it maximizes the radiation on collector surface in winter. Effect of various tilt angels at New Delhi is shown in the figure below.



Integration

Due to seasonal variation and conventional heating systems is essential with the solar water heating system. Proper integration of solar water heating system with the conventional heating systems is essential to optimally utilize the solar water heating system. In case of domestic water heating systems it is easier the options are to use the output of SWHS to input of geyser or provider a mixer for hot and cold water. In case of higher capacity SWHS integration is generally required with boiler and common practice is to use output of SWHS as makeup water in case of closed loop systems. The load pattern and requirement, e.g. in some cases part of load is for direct consumption of hot water, required to be understood for better integration of system.

Requirement for installation

The solar water heating systems requires shadow free area. The area requirement is approximately 2 - 2.5 m^2 per 100 lpd capacity.

Cost and Payback calculations

The cost of SWHS varies between Rs. 16000 – Rs 18000 per 100 lpd in case of domestic systems. In case of higher capacity system the cost varies from Rs 120 -140/ lpd.

Financing and Incentives/subsidies

The Indian Renewable Energy Development Agency (IREDA) provides loan at lower interest (8%) for systems costing more than Rs. 5Lakh. In case of systems with costs less than 5 lakh the loan is available form some designated banks as well as intermediaries. Further the SWHS are eligible for accelerated depreciation in the first year of installation of the project. In addition to this some states provide capital subsidy for SWHS.

Simple payback for domestic SWHS

Capacity: 100 lpd
Cost: Rs 18000
Energy saving: = m Cp ΔT /(kWh*geyser eff.)
= 100*4.2*35/(3600*0.8)
= 5 kWh/day
Annual savings = 5*270 = 1350 kWh/annum
= 4050 (@Rs.3.00/unit)
Payback = 17 000/4 050 = **4.1 year**

m- mass of hot water generated
Cp - heat capacity of water
ΔT - difference between water temperature and ambient

For higher capacity commercial systems:

Capacity: 1000 lpd
Cost: Rs 130 000
Tax benefit @40% of cost: Rs 52 000
Net cost: Rs 78 000
Energy saving: = m Cp ΔT /(Calorific value of oil*boiler eff.)
= 1000*4.2*35/(40320*0.75)
= **4.9 lit/day**
Annual savings = 4.9*300 lit/annum = Rs 20580 (@ Rs.14.00/lit)
Payback = 78 000/20 580 = 3.79 years

Designing and Optimization of Solar Water Heating System

Introduction

The complete designing of solar water heating system includes system design, system optimization and integration with existing heating system. Different methods have been developed for designing the solar systems, ranging from detailed simulation, simple designing methods like f-chart, to rule of thumb. At present in India, system designs are mainly based on thumb rules. Also, they are designed for the winter conditions and thus is underutilized in other seasons. For optimum sizing, CRF method is used to estimate the levelized cost of heating makeup water. Here, a typical situation, requiring integration of solar system with boiler and closed loop pressurized distribution of hot water, is considered. Thus, complete designing, optimization and integration approach is developed for the utilization of solar water heating system in large hotels as well as for similar industrial applications.

Solar water heating system

The existing system in the hotel, meeting hot water demand, includes diesel-based boiler and hot water storage tanks with closed loop pressurized distribution system. The total water-heating load can be divided into (i) makeup water heating from ambient temperature to 60°C and (ii) heat loss due to continuous circulation of hot water in the distribution circuit. The actual amount of hot water consumed is equal to the amount of makeup water added in the system. The average makeup water requirement is about 40,000 liters per day. The solar water heating system is designed to meet this load of makeup water heating. The efficiency of the existing boiler, with high-speed diesel as fuel, is 64%. The collector parameters considered for system designing (applicable for the range of flat plate collectors available in India) are:

$F_R U_L = 4.2\ W/m^2$ $\quad A_c = 2\ m^2$

$F_R(\tau\alpha) = 0.7$

The collector orientation is assumed to be south facing with a tilt angle of 40°. The radiation values and ambient conditions for Varanasi are used for designing (Anna Mani & Ranganathan, 1982).

System Size Optimization

The parameter used for optimizing the system size is the cost of heating makeup water from ambient temperature to 60°C. Capital Recovery Factor (CRF) method is used to estimate the levelized cost of makeup water heating. Out of the total makeup water-heating load L, the fraction $1-f$ is supplied by boiler, where f is the annual hot water generation by solar water heating system. The cost of this boiler fuel is included in the estimation, in addition to the operating cost of the solar water heating system. Thus,

Annual cost = annualized capital cost for SWHS + boiler fuel cost + O&M cost + running cost

From this annual cost of heating makeup water, the levelized cost is estimated. The O&M cost is taken as 2% of capital cost, while running cost is the cost of pumping in solar water heating system. The accelerated depreciation in the first year is also considered .The optimization was carried out at 12% discount rate. The values of optimum collector areas, with the levelized costs, are given below:

Discount rate	12%	Boiler fuel cost (Rs in lakh)	0.62
Optimized area (m^2)	628	O&M + operating cost (Rs in lakh)	0.84
Capital cost (Rs in lakh)	43.96	Levelized cost of makeup water Heating (paise/lit)	3.66
Annualized cost (Rs in lakh)	3.87		

System Integration

The existing system for water heating includes boiler, hot water storage tanks and a pressurized closed loop distribution system, as shown in figure 1. The pressure on the distribution side is maintained by operating the booster pump continuously. Also, when the temperature in the storage tanks depose below 55°C, the boiler is fired to maintain the temperature and makeup water is added whenever the water level in the tank drops below a certain level. Thus the pressure and temperature in the distribution network is always maintained. Solar water heating system thus can only be used to provide the pre-heated makeup water. Any other arrangement of introducing hot water into the pressurized closed loop distribution system will require complicated controlling mechanism for maintaining pressure and temperature in the hot water distribution circuit.

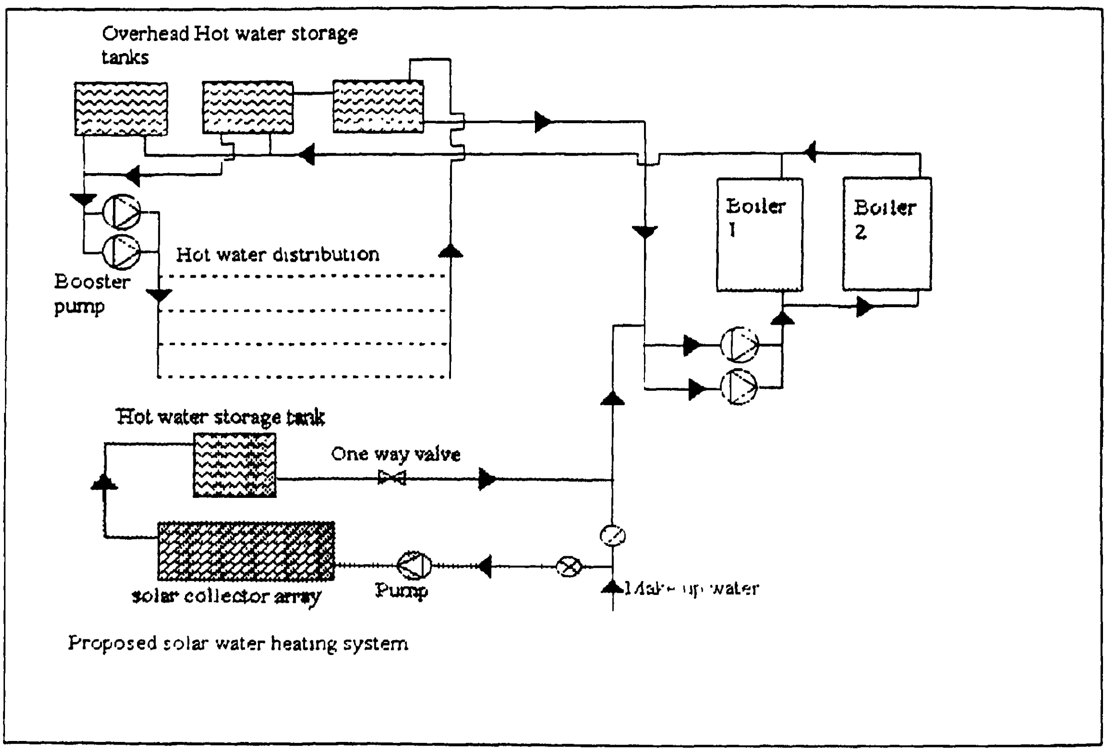


Figure 1 Line diagram of existing water heating arrangement with proposed SWHS

Inferences and discussion

It was observed that the simple payback period varies linearly with absorber area, between 2.8 to 3.2 years. System optimization using these parameters is not possible. Thus, for optimization of system size, levelized cost of heating makeup water is used. It was found that the optimum system size depends upon the collector parameters and the ambient conditions. Variation in the levelized cost with absorber area from 300 m² to 800 m² shown in figure 2. The optimum system size is found to be 628 m² of absorber area. In this fashion, based on the applicable discount rate, the optimum size of the solar water heating system can be obtained

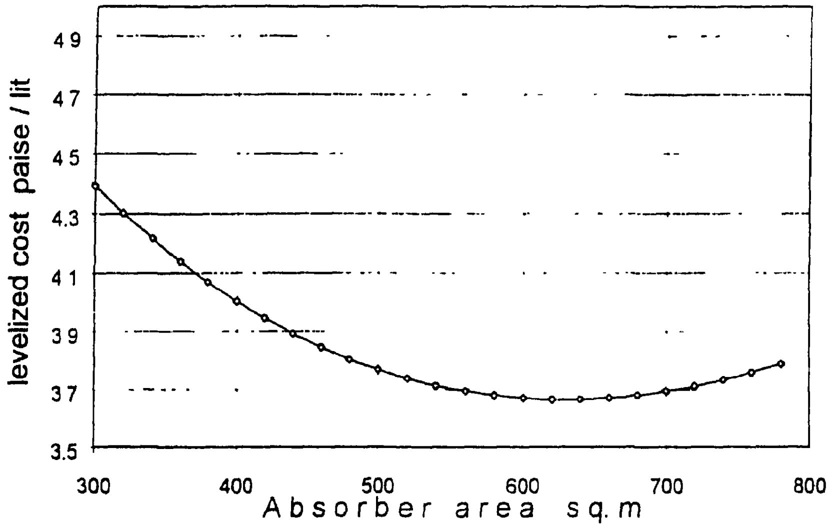


Figure 2: Levelized cost variation with absorber area

The system size estimation done by the conventional methods, the absorber area works out to be 700-720 m². These systems are designed on the basis of ambient conditions in the winter months. It is evident that the system with 700 m² absorber area is over designed except for four monsoon months and two extreme winter months.

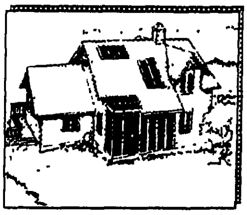
Nomenclature

A_c - absorber area (m²)
F_R - collector heat removal factor
f - fraction of load supplied by solar heating system
H_T - monthly average daily radiation incident on absorber (J/m²)
L - makeup water heating load (J)
N - days in month
Ta - monthly average ambient temperature
T_{ref} - empirically derived reference temperature (100°C)
t_s - number of seconds in month
U_L - collector overall heat loss coefficient (W/m² °C)
$\tau\alpha$ - transmittane absorptance product

References

1. Anna Mani and S. Rangarajan (1982)"Solar Radiation Over India" Allied Publishers Pvt. Ltd.Duffie
2. J. A. and Beckman W.A.(1991). "Solar Engineering of Thermal Processes"

SOLAR WATER HEATING SYSTEM - TECHNOLOGY, DESIGN, SIZING AND EXAMPLES TO HIGHLIGHT ARCHITECTURAL INTEGRATION



Mrinal Krishna Chaudhury
Scientific Officer (Energy)
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ASTEC

Harnessing Solar Energy

THE TWO BASIC METHODS OF HARNESSING SOLAR ENERGY ARE THROUGH

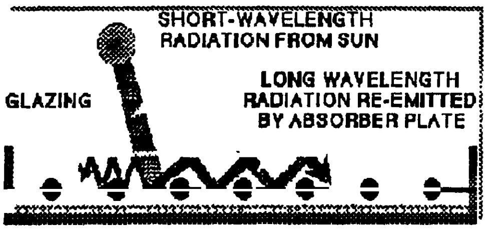
1. **SOLAR THERMAL SYSTEMS AND**
2. **SOLAR ELECTRIC SYSTEMS.**

- Solar thermal systems convert the radiant energy of the sun into heat, and then use that heat energy as desired
- Solar electric systems convert the radiant energy of the sun directly into electrical energy, which can then be used as most electrical energy is used today

---

SOLAR THERMAL SYSTEMS
How do they work?

- LOW TEMPERATURE SOLAR THERMAL TECHNOLOGIES ESPECIALLY THOSE THAT DO NOT GENERATE ELECTRICITY RELY ON THE SCIENTIFIC PRINCIPLES BEHIND THE **GREENHOUSE EFFECT** TO GENERATE HEAT
- ELECTROMAGNETIC RADIATION FROM THE SUN INCLUDING VISIBLE AND INFRA RED WAVELENGTHS PENETRATES INTO THE COLLECTOR WHICH IS ABSORBED BY THE SURFACES INSIDE THE COLLECTOR
- ONCE RADIATION IS ABSORBED BY THE SURFACES WITHIN THE COLLECTOR THE TEMPERATURE RISES THIS INCREASE IN TEMPERATURE CAN BE USED TO HEAT WATER


SHORT-WAVELENGTH RADIATION FROM SUN
GLAZING
LONG WAVELENGTH RADIATION RE-EMITTED BY ABSORBER PLATE

GREENHOUSE EFFECT INSIDE A SOLAR FLAT PLATE COLLECTOR

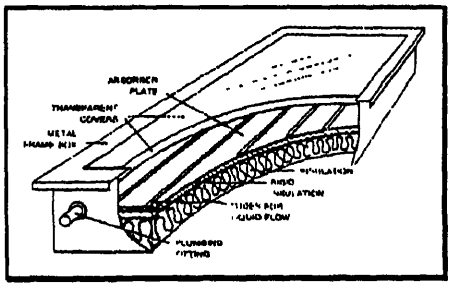
DOMESTIC SOLAR HOT WATER SYSTEMS

DOMESTIC SOLAR HOT WATER SYSTEMS CAN BE DIVIDED INTO TWO GROUPS·

- FLAT PLATE COLLECTORS TYPE
- BATCH TYPE WATER HEATERS

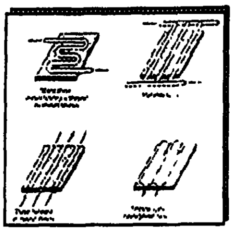
FLAT PLATE COLLECTORS (FPCs) ARE THE MOST COMMONLY USED ARRANGEMENT FOR DOMESTIC SYSTEMS AND AS SUCH WILL FORM THE LARGEST SECTION OF THIS INFORMATION

FLAT PLATE COLLECTORS

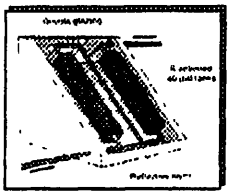


Flat plate collectors

- **Flat plate collectors are sophisticated greenhouses that trap and use the heat from the Sun to raise the temperature of water up to about 70° C**
- **These collectors consist of airtight boxes with a glass, or other transparent material cover. Several designs on the arrangement of the internal tubing of flat plate collectors**

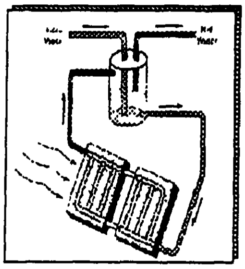


BATCH TYPE SOLAR WATER HEATER



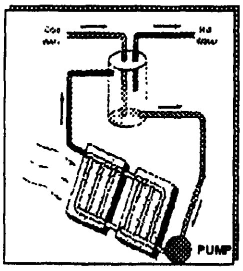
Batch systems consist of black storage tanks contained within an insulated box that has a transparent cover. Cold water is added to the hot water stored in the tanks whenever hot water is removed

THERMOSYPHON WATER HEATER



Thermosyphoning utilises flat plate collector to heat the water which is then returned to a storage tank located above the collector Cold denser water flows through the collector heating up and is then returned to the tank As the heated water is less dense it rises to the top of the tank In full Sun, a single pass through the collector can heat the water by as much as 20°C

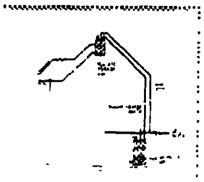
FORCED FLOW SYSTEM



When the capacity of the Solar Water Heater is higher say beyond 1000 LPD or depending on the layout of the collectors it is not possible for the fluid to automatically circulate within the system the circulation of the fluid is enhanced by the use of a pump

Such systems are also called ACTIVE SYSTEMS'

INTEGRATING THE SOLAR WATER HEATER WITH AUXILLARY HEATING



[illegible] with built in [illegible] element

Due to seasonal variation proper integration of the SHWS with conventional heating systems is essential for optimal use

OPTIONS:

Domestic- to use output of SHWS to input of geysers

Higher Capacity- integration generally required with boiler where common practice is output of SHWS is used as makeup water

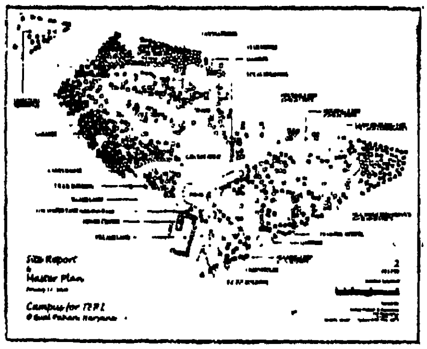
Retreat : a unique experience in sustainable building design

Mili Majumdar

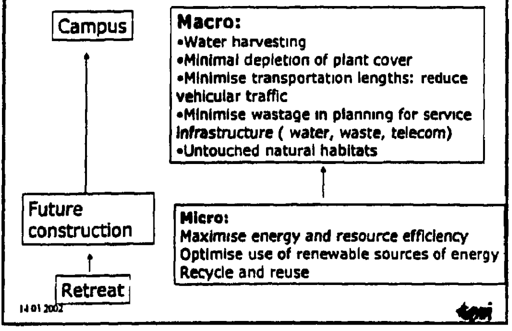
Sustainable development

- Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs

- *Brundtland commission*



Sustainable habitat at Gual pahari: Macro and micro planning considerations



Campus

Macro:
- •Water harvesting
- •Minimal depletion of plant cover
- •Minimise transportation lengths: reduce vehicular traffic
- •Minimise wastage in planning for service infrastructure (water, waste, telecom)
- •Untouched natural habitats

Future construction

Micro:
Maximise energy and resource efficiency
Optimise use of renewable sources of energy
Recycle and reuse

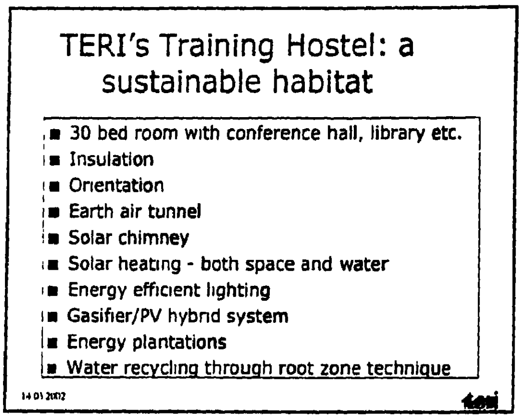
Retreat

Why RETREAT?

- TERI's vision on sustainable habitat transformed to reality
- Model habitat design of high equilibrium (with high level of thermal and visual comfort) with minimal environmental footprint ,replicable in part or whole
- Addressing various issues related to building/habitat design and seek environment friendly answers to these.
- Showcase energy efficient options which are cost effective as well as environment friendly
- Learn and disseminate

Sustainable habitat-zero energy in, zero waste out

- Minimize demand (use of passive techniques suitable for the particular climate)
- Use of environment friendly construction materials and techniques
- Meet the loads by efficient equipment
- Use of onsite sources and sinks
- Meet part of the load by renewable energy sources (determined by techno-economic viability)
- Minimize generation of waste and recycle waste
- Maximise water conservation and waste water treatment



TERI's Training Hostel: a sustainable habitat

- 30 bed room with conference hall, library etc.
- Insulation
- Orientation
- Earth air tunnel
- Solar chimney
- Solar heating - both space and water
- Energy efficient lighting
- Gasifier/PV hybrid system
- Energy plantations
- Water recycling through root zone technique

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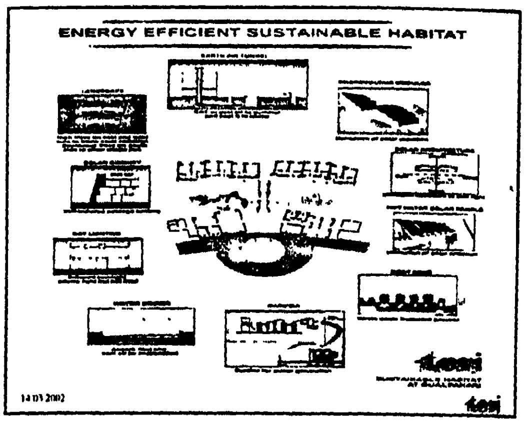

ENERGY EFFICIENT SUSTAINABLE HABITAT

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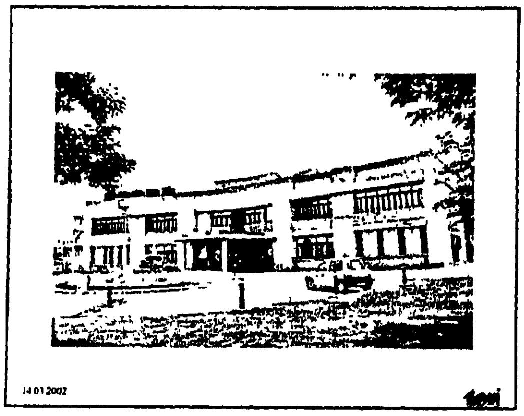

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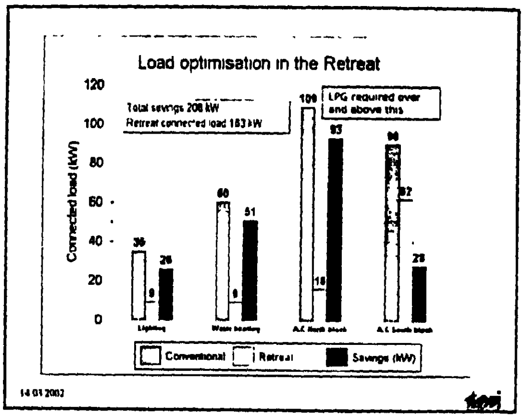

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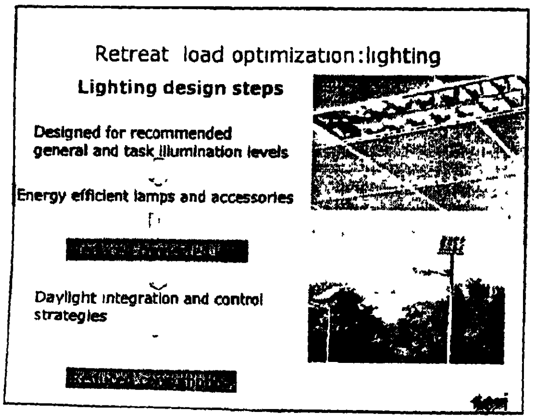


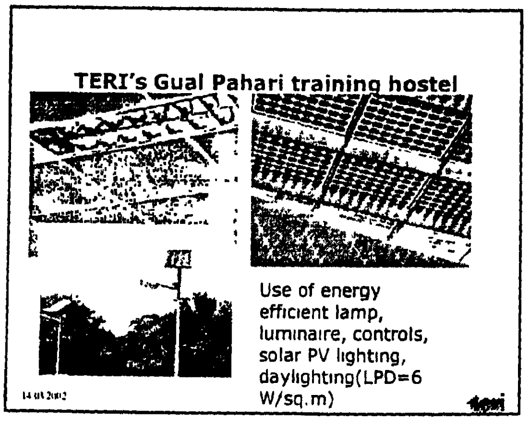
Retreat load optimization: lighting

Lighting design steps

Designed for recommended general and task illumination levels

Energy efficient lamps and accessories

Daylight integration and control strategies



TERI's Gual Pahari training hostel

Use of energy efficient lamp, luminaire, controls, solar PV lighting, daylighting(LPD=6 W/sq.m)

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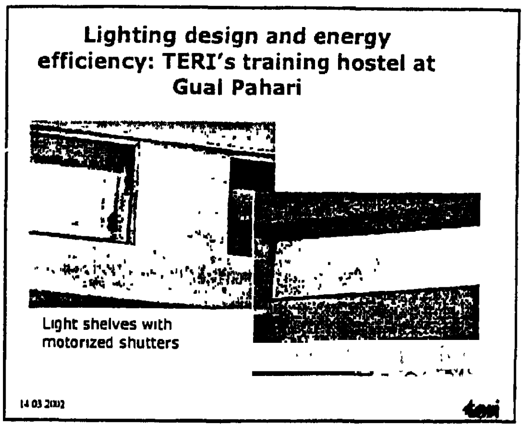

Lighting design and energy efficiency: TERI's training hostel at Gual Pahari

Light shelves with motorized shutters

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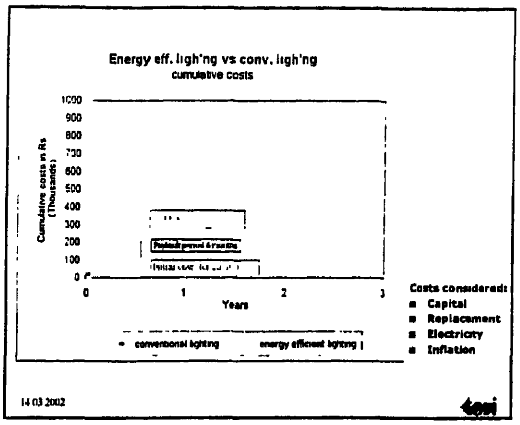

Energy eff. ligh'ng vs conv. ligh'ng
cumulative costs

Costs considered:

- Capital
- Replacement
- Electricity
- Inflation

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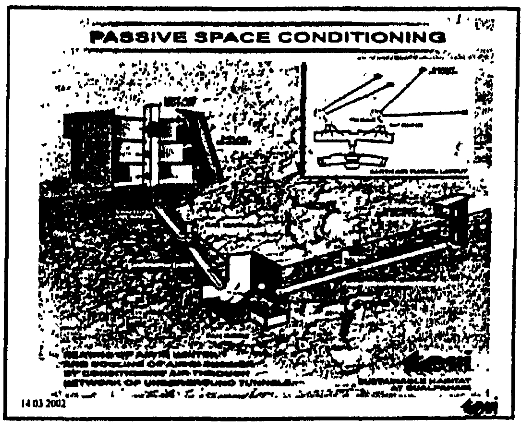

PASSIVE SPACE CONDITIONING

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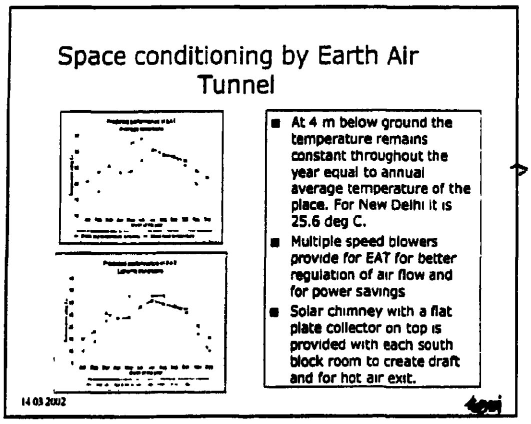

Space conditioning by Earth Air Tunnel

- At 4 m below ground the temperature remains constant throughout the year equal to annual average temperature of the place. For New Delhi it is 25.6 deg C.
- Multiple speed blowers provide for EAT for better regulation of air flow and for power savings
- Solar chimney with a flat plate collector on top is provided with each south block room to create draft and for hot air exit.

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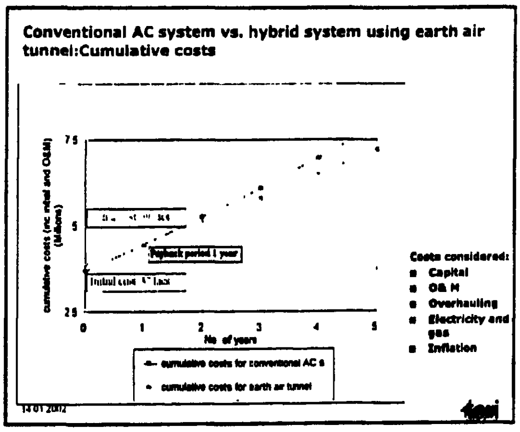

Conventional AC system vs. hybrid system using earth air tunnel:Cumulative costs

Costs considered:

- Capital
- O& M
- Overhauling
- Electricity and gas
- Inflation

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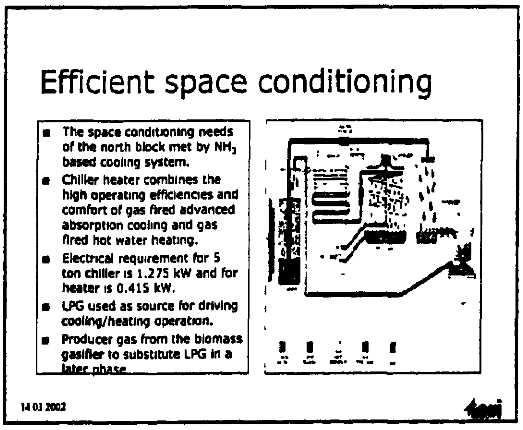

Efficient space conditioning

- The space conditioning needs of the north block met by NH_3 based cooling system.
- Chiller heater combines the high operating efficiencies and comfort of gas fired advanced absorption cooling and gas fired hot water heating.
- Electrical requirement for 5 ton chiller is 1.275 kW and for heater is 0.415 kW.
- LPG used as source for driving cooling/heating operation.
- Producer gas from the biomass gasifier to substitute LPG in a later phase.

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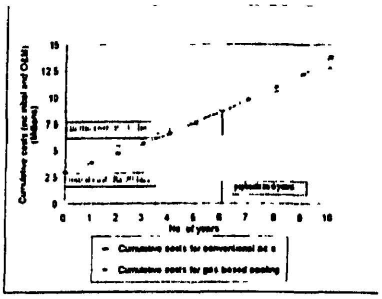
Ammonia absorption chillers

- Direct fired chillers eliminate use of boilers and water treatment plant
- CFC free
- Air cooled system
- low operating cost and negligible maintenance
- Noiseless and vibration free (roof top installation possible)

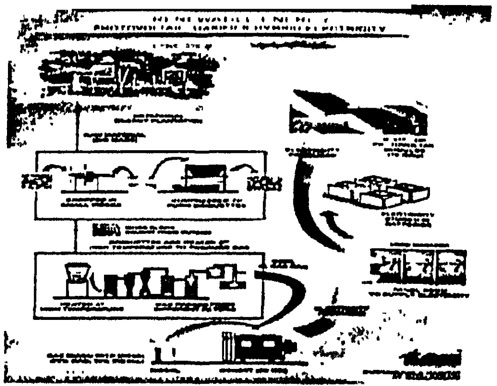
Conventional A.C system vs. Ammonia absorption chiller based system: Cumulative costs



Costs considered:

- Capital
- O& M
- Overhauling
- Electricity and gas
- Inflation

Integration of solar water heating system



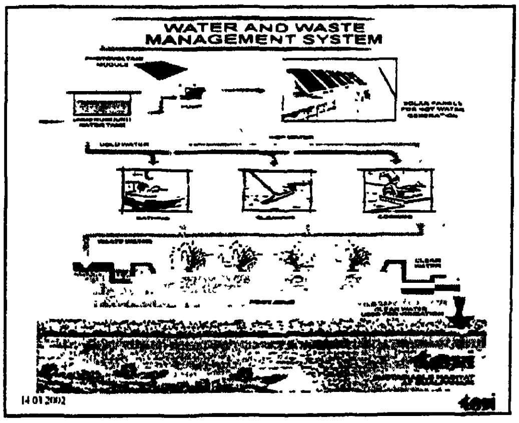
Cost of electricity generation from PV-gasifier hybrid system

- PV- gasifier hybrid: Rs.6.34/kWh generated
- PV alone: Rs.54.4/kWh generated

Renewable energy systems

- Solar hot water system 2000 lpd at 65 deg C
- 24 nos solar collectors integrated with parapet wall for cost reduction
- Backup for winter days through producer gas from gasifier

- Powered by hybrid system of 50kW gasifier and 10kW photovoltaic plant
- System is controlled by load management system which is backed by batteries and bi directional inverter for maximum use of available energy
- Daytime loads are met by the gasifier
- Nighttime loads met by batteries which are charged by PV throughout the day
- PV integrated into building
- PV powered street lights
- PV powered pumping system



WATER AND WASTE MANAGEMENT SYSTEM

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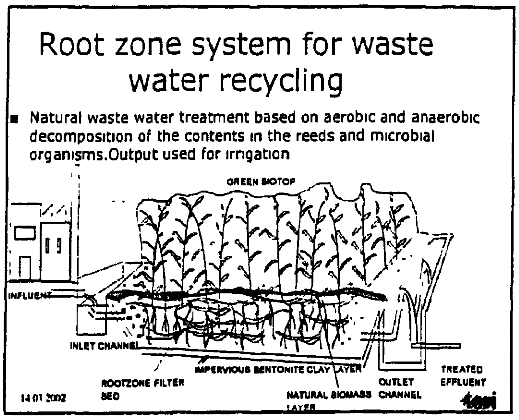

Root zone system for waste water recycling

- Natural waste water treatment based on aerobic and anaerobic decomposition of the contents in the reeds and microbial organisms.Output used for irrigation

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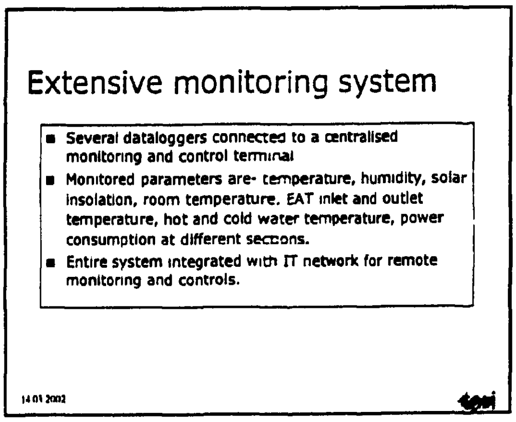

Extensive monitoring system

- Several dataloggers connected to a centralised monitoring and control terminal
- Monitored parameters are- temperature, humidity, solar insolation, room temperature. EAT inlet and outlet temperature, hot and cold water temperature, power consumption at different sections.
- Entire system integrated with IT network for remote monitoring and controls.

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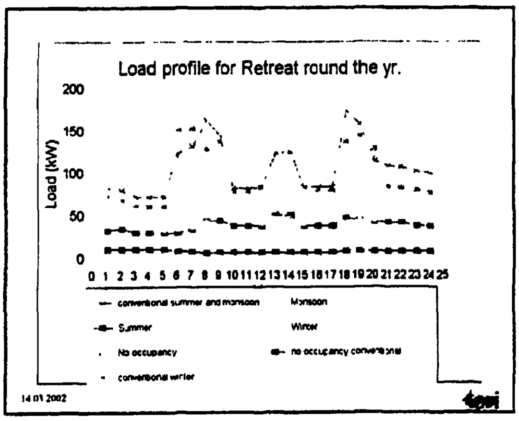

Load profile for Retreat round the yr.

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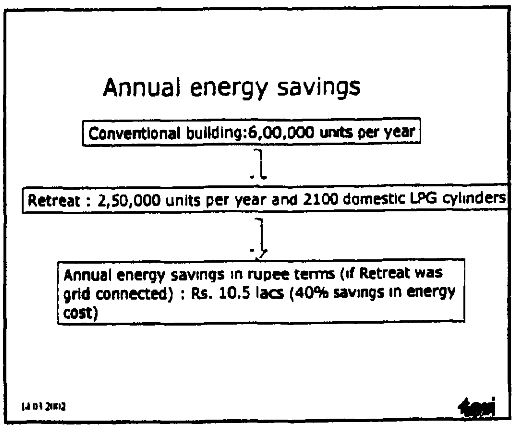

Annual energy savings

Conventional building:6,00,000 units per year

Retreat : 2,50,000 units per year and 2100 domestic LPG cylinders

Annual energy savings in rupee terms (if Retreat was grid connected) : Rs. 10.5 lacs (40% savings in energy cost)

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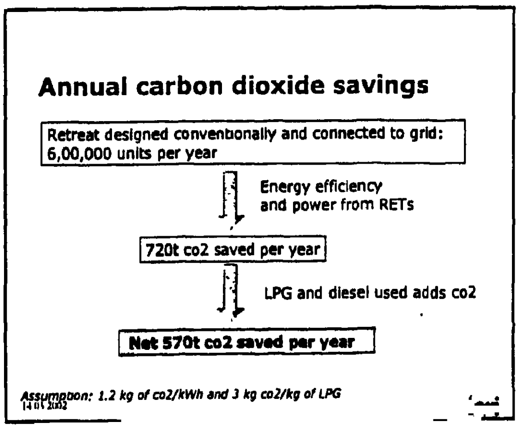

Annual carbon dioxide savings

Retreat designed conventionally and connected to grid: 6,00,000 units per year

Energy efficiency and power from RETs

720t co2 saved per year

LPG and diesel used adds co2

Net 570t co2 saved per year

Assumption: 1.2 kg of co2/kWh and 3 kg co2/kg of LPG

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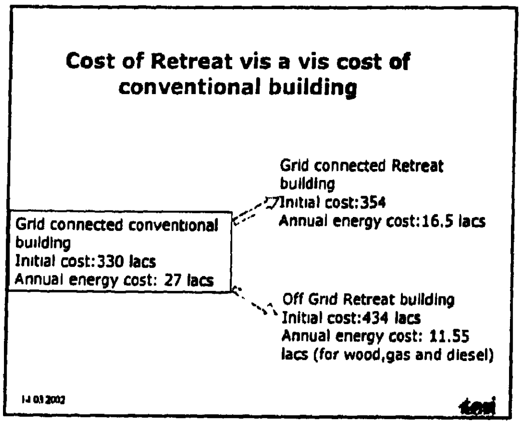

Cost of Retreat vis a vis cost of conventional building

Grid connected conventional building
Initial cost:330 lacs
Annual energy cost: 27 lacs

Grid connected Retreat building
Initial cost:354
Annual energy cost:16.5 lacs

Off Grid Retreat building
Initial cost:434 lacs
Annual energy cost: 11.55 lacs (for wood,gas and diesel)

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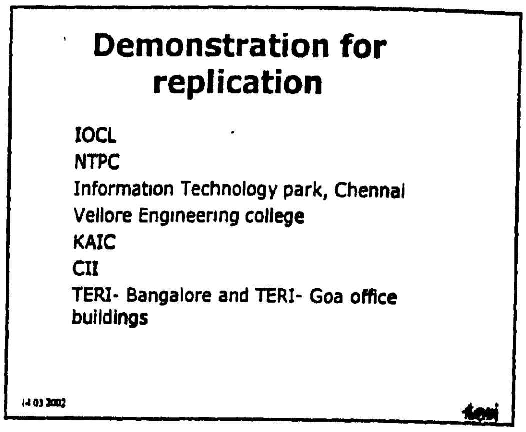

Demonstration for replication

IOCL
NTPC
Information Technology park, Chennai
Vellore Engineering college
KAIC
CII
TERI- Bangalore and TERI- Goa office buildings

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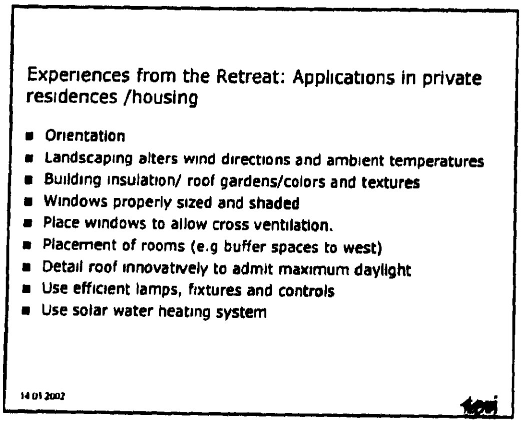

Experiences from the Retreat: Applications in private residences /housing

- Orientation
- Landscaping alters wind directions and ambient temperatures
- Building insulation/ roof gardens/colors and textures
- Windows properly sized and shaded
- Place windows to allow cross ventilation.
- Placement of rooms (e.g buffer spaces to west)
- Detail roof innovatively to admit maximum daylight
- Use efficient lamps, fixtures and controls
- Use solar water heating system

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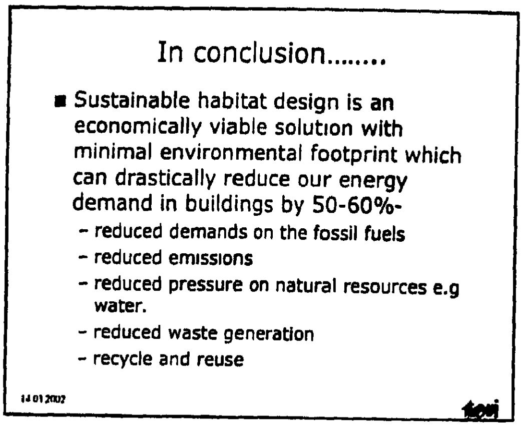

In conclusion……..

- Sustainable habitat design is an economically viable solution with minimal environmental footprint which can drastically reduce our energy demand in buildings by 50-60%-
  - reduced demands on the fossil fuels
  - reduced emissions
  - reduced pressure on natural resources e.g water.
  - reduced waste generation
  - recycle and reuse

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Daylighting-Design and integration with artificial lighting

Mili Majumdar
Fellow
Energy Environment Technology
TERI

Structure of presentation

- What is daylighting?
- Design tools for daylight integration into buildings
- Daylighting components.
- Integration of daylighting with artificial lighting
- Case studies

Daylighting

- Daylight is a natural source of light which meets all requirements of good lighting
- Has major effect on the appearance of space and energy efficiency implications
- Variability and subtlety is pleasing to the occupants in contrast to the relatively monotonous environment produced by artificial light.
- Daylighting is important particularly in day use buildings.

Daylighting -contd....

- The orientation, space organisation, and geometry of the space to be lit.
- The location, form, and dimensions of the fenestration
- The location and surface properties of internal partitions which affect daylight distribution
- The location, form, an dimensions of shading devices
- The light and thermal characteristics of the glazing materials.

Considerations / requirements for daylighting

- ***Degree to which daylighting can be implemented***
  - **Geographical location**
  - **Site characteristics**
  - **Orientation**
- **Even distribution of light**
- **Daylighting impact on the thermal performance of the building**

Mechanisms to implement daylighting

- **Vertical windows**
- **Roof lighting**
- **Light ducts**

Daylighting linking controls

- **Photoelectric switching**
- **Photoelectric dimming**

Daylight factor method

- Light reaching a point inside building comprises: direct light, diffuse or skylight, externally reflected light and internally reflected light.
- DF= SC+ERC+IRC= Ei/Eo X100
- E_i = indoor illumination at the point of consideration
- E_o = outdoor illumination from unobstructed sky hemisphere

- **Sky component (SC)** – The area of sky visible from the point considered and its average altitude angle (luminance of the sky at that angle), window size and position in relation t the point, thickness of window frame, quality of glass and its clearness, and any external obstructions.

- **Externally reflected component (ERC)** - The area of external surfaces visible from the point considered and reflectance of these surfaces.
- **Internally reflected component (IRC)** - The size of the room, the ratio of surfaces (wall, roof, etc.) in relation to the window area and reflectance of indoor surfaces.
- For India, it is taken as 8,000 lux for clear design sky

Recommended daylight factors

Building Area/activity	*Daylight factor (%)*
Dwellings Kitchen	2.5
Living room	0.625
Study room	1.9
Circulation	0.313
Schools Class room	1.9-3.8
Laboratory	2.5-3.8
Offices General	1.9
Drawing, typing	3.75
Enquiry	0.625-1.9
Hospitals General wards	1.25
Pathology laboratory	2.5-3.75
Libraries Stack room	0.9-1.9
Reading room	1.9-3.75
Counter area	2.5-3.75
Catalogue room	1.9-2.5

Daylight design based on results of International daylight measurement programme

- Data required for daylight design
  - Sky illuminance (Diffuse)
  - Solar illuminance (Direct)
  - Sky luminance distribution
- Hourly variation of illuminance data for different latitudes have been determined.
- Window area determined for a particular latitude and face of building based on:
  - Sky & solar illuminance on horizontal
  - Atmosphere turbidity
  - Ground reflectance
  - Reflectance of room surfaces
  - Net/gross window area (f)
  - Maintenance factor (Mg)
  - Transmittance of glass (T)
  - Reduction due to louvres, etc.s (S)

- For a given general illuminate value of 100 lux in a room of area A and room surface area of Ar, window area as %age of floor area (F) is

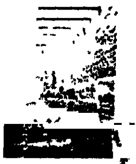
$$\frac{Ex(\text{direct light illuminance on window plane}) \times f \times F \times A \times Mg \times T \times S\,Rav}{100Ar(1-Rav)} \times 100$$

- The general illuminace indoor will be augmented by sky illuminance as contributed by visible patch of sky from given location
- p × sky illuminance × sky factor × f × Mg ×TRS/100.

Adeline Demo

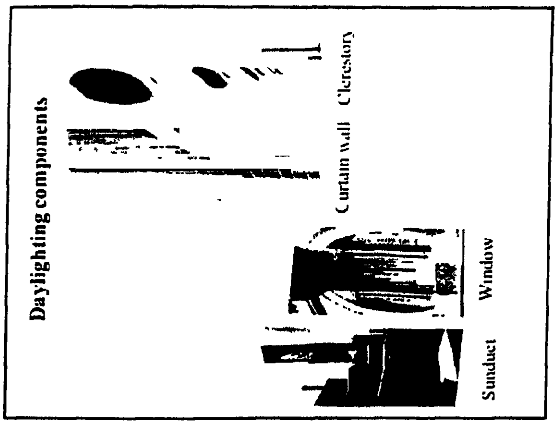
Daylighting components

Atrium


Light duct

Gallery

Porch



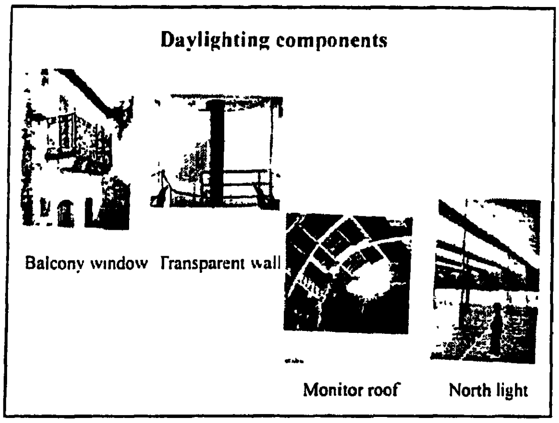
Daylighting components

Curtain wall

Clerestory

Sunduct

Window



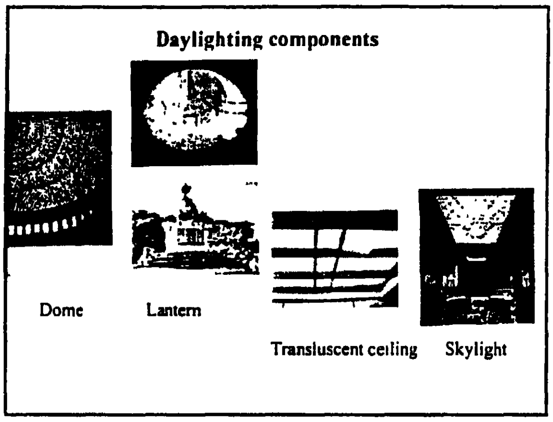
Daylighting components

Balcony window

Transparent wall

Monitor roof

North light



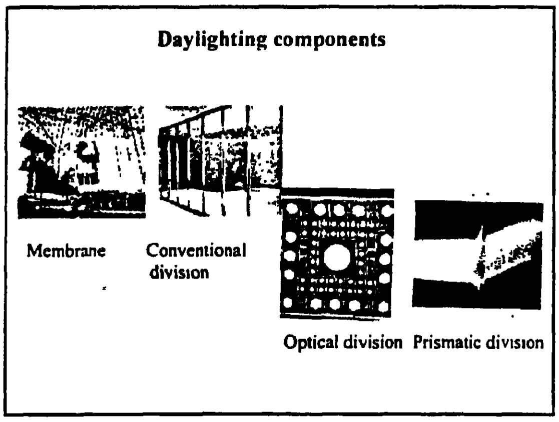
Daylighting components

Dome

Lantern

Transluscent ceiling

Skylight



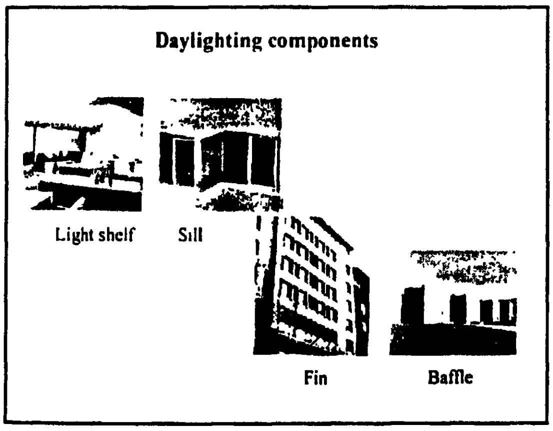
Daylighting components

Membrane

Conventional division

Optical division

Prismatic division



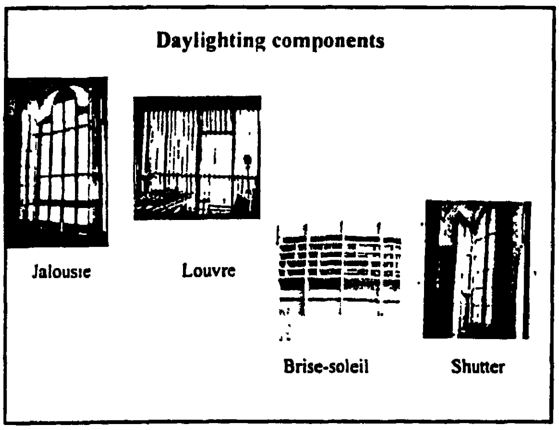
Daylighting components

Light shelf

Sill

Fin

Baffle



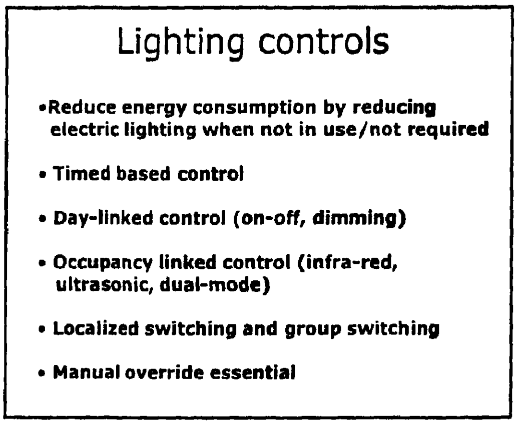
Daylighting components

Jalousie

Louvre

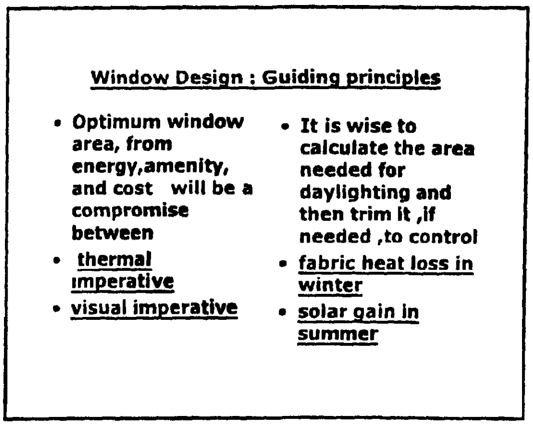
Brise-soleil

Shutter



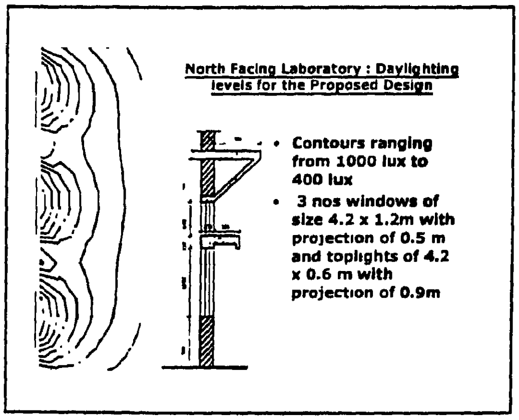
Lighting controls

- Reduce energy consumption by reducing electric lighting when not in use/not required
- Timed based control
- Day-linked control (on-off, dimming)
- Occupancy linked control (infra-red, ultrasonic, dual-mode)
- Localized switching and group switching
- Manual override essential



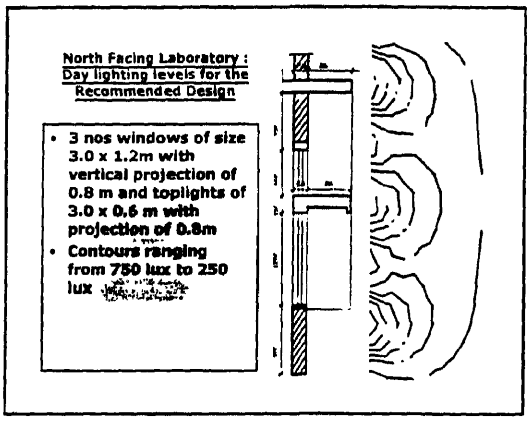
Window Design : Guiding principles

- Optimum window area, from energy,amenity, and cost will be a compromise between
- thermal imperative
- visual imperative
- It is wise to calculate the area needed for daylighting and then trim it ,if needed ,to control
- fabric heat loss in winter
- solar gain in summer



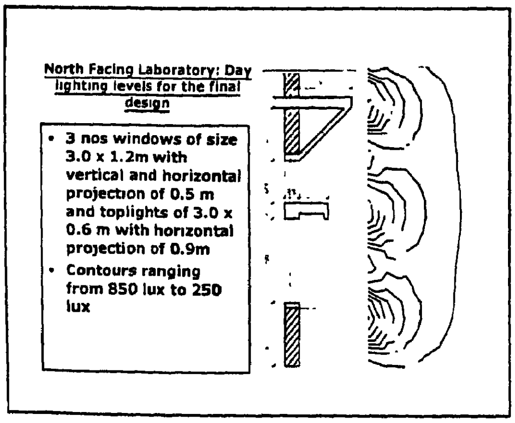
North Facing Laboratory : Daylighting levels for the Proposed Design

- Contours ranging from 1000 lux to 400 lux
- 3 nos windows of size 4.2 x 1.2m with projection of 0.5 m and toplights of 4.2 x 0.6 m with projection of 0.9m



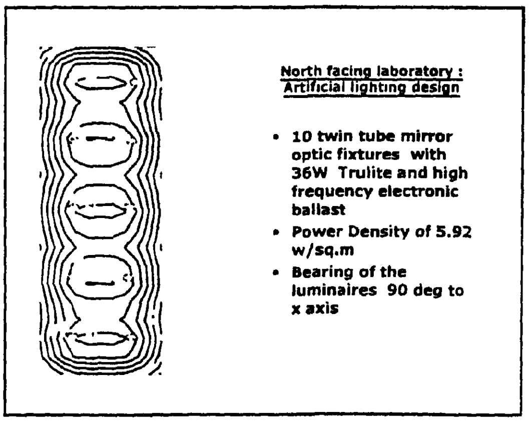
North Facing Laboratory : Day lighting levels for the Recommended Design

- 3 nos windows of size 3.0 x 1.2m with vertical projection of 0.8 m and toplights of 3.0 x 0.6 m with projection of 0.8m
- Contours ranging from 750 lux to 250 lux



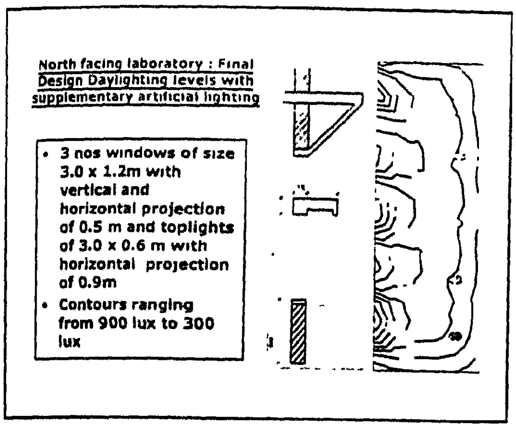
North Facing Laboratory: Day lighting levels for the final design

- 3 nos windows of size 3.0 x 1.2m with vertical and horizontal projection of 0.5 m and toplights of 3.0 x 0.6 m with horizontal projection of 0.9m
- Contours ranging from 850 lux to 250 lux



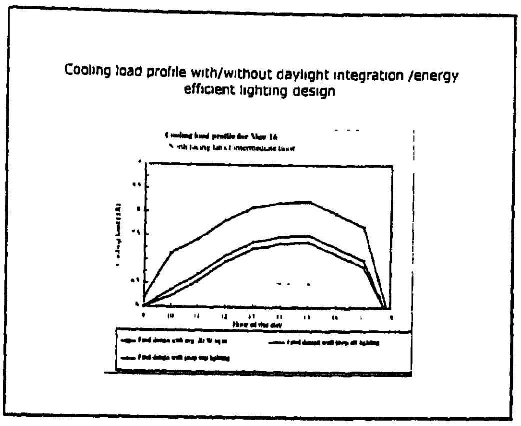
North facing laboratory : Artificial lighting design

- 10 twin tube mirror optic fixtures with 36W Trulite and high frequency electronic ballast
- Power Density of 5.92 w/sq.m
- Bearing of the luminaires 90 deg to x axis

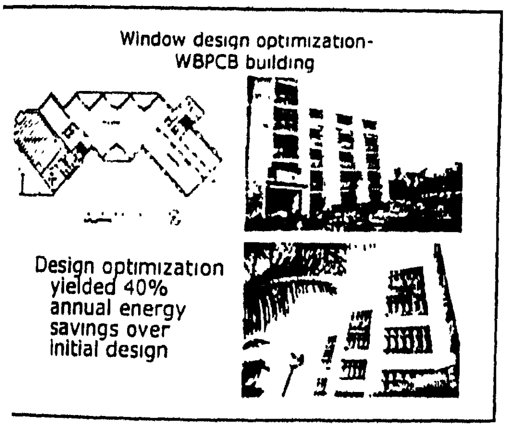


North facing laboratory : Final Design Daylighting levels with supplementary artificial lighting

- 3 nos windows of size 3.0 x 1.2m with vertical and horizontal projection of 0.5 m and toplights of 3.0 x 0.6 m with horizontal projection of 0.9m
- Contours ranging from 900 lux to 300 lux

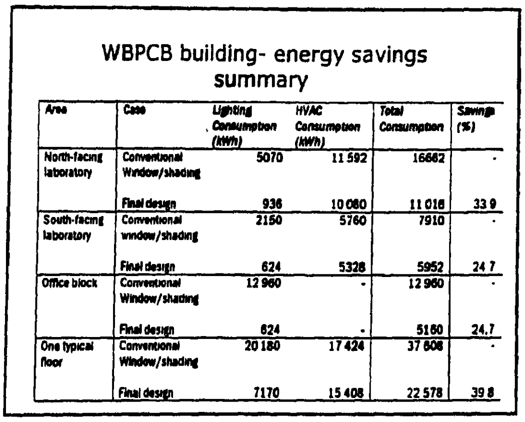


Cooling load profile with/without daylight integration /energy efficient lighting design



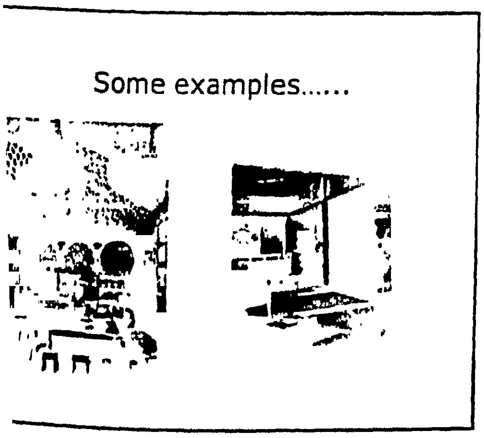
Window design optimization- WBPCB building

Design optimization yielded 40% annual energy savings over initial design

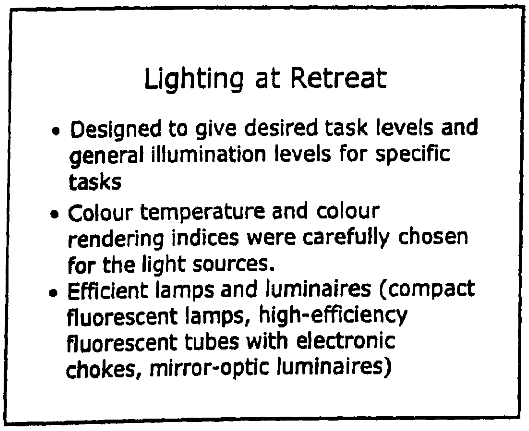


WBPCB building- energy savings summary

Area	Case	Lighting Consumption (kWh)	HVAC Consumption (kWh)	Total Consumption	Savings (%)
North-facing laboratory	Conventional Window/shading	5070	11 592	16682	-
	Final design	936	10 080	11 016	33 9
South-facing laboratory	Conventional window/shading	2150	5760	7910	-
	Final design	624	5328	5952	24 7
Office block	Conventional Window/shading	12 960	-	12 960	-
	Final design	624	-	5160	24.7
One typical floor	Conventional Window/shading	20 180	17 424	37 608	-
	Final design	7170	15 408	22 578	39 8



Some examples……



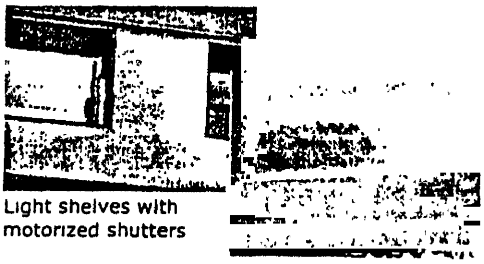
Lighting at Retreat

- Designed to give desired task levels and general illumination levels for specific tasks
- Colour temperature and colour rendering indices were carefully chosen for the light sources.
- Efficient lamps and luminaires (compact fluorescent lamps, high-efficiency fluorescent tubes with electronic chokes, mirror-optic luminaires)

Lighting at Retreat

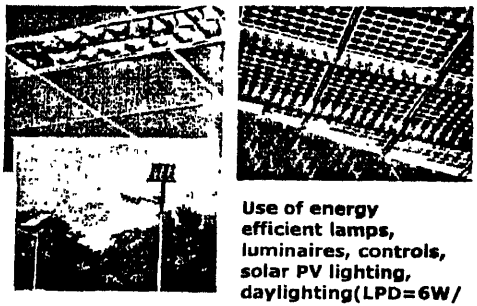
- Daylight integration with artificial lighting
- Efficient control systems for switching the lights off when not required, e.g. a timer to switch off the lights in corridors at night, a timer to control external lights; key-tag switches for guest rooms, and occupancy sensors in the public toilets.
- Reducing the number of lamps in guest bedrooms by using the swivel-type luminaires, which serves as a table lamp for reading as well as a bed-side lamp.

Lighting design and energy efficiency: RETREAT



Light shelves with motorized shutters

RETREAT, Gual Pahari



Use of energy efficient lamps, luminaires, controls, solar PV lighting, daylighting(LPD=6W/ sq.m)

BAMBOO: A PROSPECTIVE LOW-ENERGY BUILDING MATERIAL.

When we talk about energy efficient building, we should consider basically the following five factors as a whole if we consider total efficiency.

1. Energy consumed during production of the material used for the building.
2. Energy consumed in transportation of the material for building.
3. Energy consumed for shaping of the material and in the system of construction
4. Energy consumed for living comfort during the use of the building.
5. Probable energy to be consumed to dissipate the used building material after the building has lasted for its life, i.e., bio-degradable/eco-friendly and energy retrievable materials will add to the total energy efficiency of the building.

Bamboo proves to be a suitably befitting material for all the above factors.

Now, what type of buildings can we expect from bamboo as the basic building material?

Because a bamboo house generally brings the image of a rural house of semi-permanent or temporary nature which is always branded as a low-cost house and with the social stigma that bamboo is only poor man's timber. Where will the factor four, listed above, i.e. HVAC (Heating Ventilating Air Conditioning) effect a bamboo house? Can we design a building with bamboo as the basic material, for energy efficiency, for all the components of the building? If yes, how? And if not, to what extent?

To explore the possibility of using bamboo in a better and respectful (to upgrade the status of the material) way a try was made as far back as 1970-71 followed by few experiments done intermittently (due to lack of general awareness about the material and lack of fund). And then there is a further follow-up by a recent venture into the field of construction, which is still in process. All these have been documented in a book ' BAMBOO IN THE FIELD OF CONSTRUCTION IN NORTH EAST INDIA '. This document asserts that BAMBOO which is as old as timber in Nature is a very versatile material and is fast gaining ground while heading towards it's recognition as a suitable building material with it's potential to demand for global standardization of technical data on it.

It is relevant to welcome the global movement for recognition of BAMBOO as a suitable building material because it is eco-friendly and highly suitable for energy efficiency of a building.

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